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Raytrace Technique for a Laterally Heterogeneous Environment—Software Document

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ADMINISTRATIVE INFORMATION

This publication includes four documents produced by members of the Tropospheric Branch, Code 543, Naval Ocean Systems Center, for Space and Naval Warfare Systems Command, Washington, DC.

These documents are the Operational Concept, Software Requirements Specification, Software Design, and Software Test Description for the Raytrace technique for a laterally heterogenous environment. They are published in accordance with standards set by the Naval Oceanographic Office in "Software Documentation Standards and Coding Requirements for Environmental System Product Development," September 1988.

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JG

OPERATIONAL CONCEPT DOCUMENT

FOR THE

RAYTRACE TECHNIQUE FOR A LATERALLY

HETEROGENEOUS ENVIRONMENT

30 September 1990

Prepared for:

Space and Naval Warfare Systems Command (PMW-141)

Prepared by:

Tropospheric Branch
Ocean and Atmospheric Sciences Division
Naval Ocean Systems Center
San Diego, CA 92152-5000

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Raytrace technique for a laterally heterogeneous environment.

1.2 Purpose

Electromagnetic (EM) wave propagation is the transmission of an EM wave between a transmitter and a receiver. If a particular point on the wave front is followed over time, the collection of point positions would define a ray. The ray would coincide with a line from the transmitter to the receiver, as illustrated in figure 1.1-1. The purpose of this raytrace technique is to describe an EM wave's path in terms of rays, as the wave propagates through a laterally heterogeneous medium where the index of refraction is allowed to vary both vertically and horizontally.

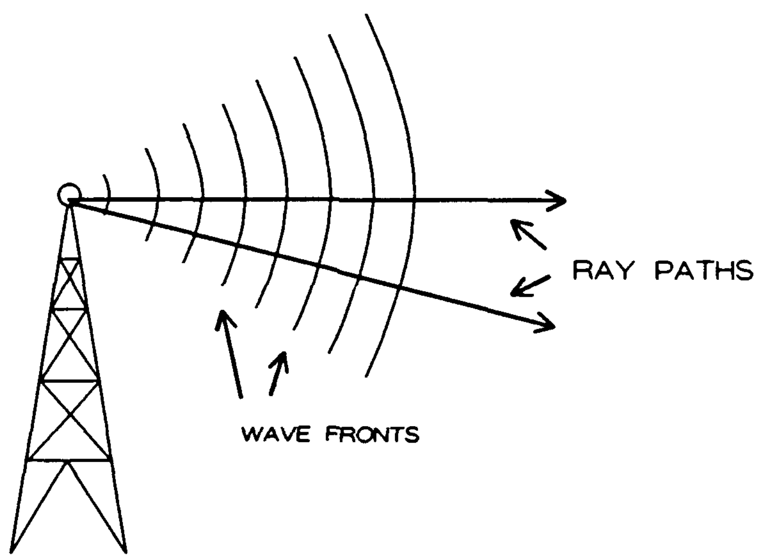

Figure 1.1-1. EM wave front and ray relationship.

1.3 Introduction

This document describes a raytrace technique and the requirements that drive its development. Several Tactical Environmental Support System (TESS) (3) Computer Software Configuration Items (CSCI) employ raytrace techniques. The raytrace technique described within this document may be used within these CSCI's when the propagation medium's refractive index is laterally heterogeneous.

2.0 REFERENCE DOCUMENTS

(a) Commander-In-Chief, Pacific Fleet Meteorological Requirement (PAC MET) 87-04, "Range Dependent Electromagnetic Propagation Models."

(b) Naval Oceanographic Office, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," Sep. 1988.

(c) Naval Ocean Systems Center (NOSC) Technical Report 1180, "A Raytrace Method for a Laterally Heterogeneous Environment," Jul. 1987.

3.0 MISSION

3.1 Mission Need Requirements

Propagation models are required to provide tactically useful information for Battle Group disposition of sensors, emitters, and weapon systems. Presently, many EM wave propagation models do not allow for refractive conditions that vary with range. New propagation models and tactical decision aid displays are required that are range dependent.

3.2 Primary Mission

The raytrace technique will describe an EM wave's path as the wave propagates through a laterally heterogeneous medium where the

index of refraction is allowed to vary both vertically and horizontally.

4.0 SYSTEM FUNCTIONS AND CHARACTERISTICS

4.1 System Functions

The raytrace technique provides a means to assess an EM wave's path as it propagates through a laterally heterogeneous medium where the index of refraction is allowed to vary both vertically and horizontally.

4.2 Computer System Functions

The calling TESS CSCI provides EM system and environmental data to the raytrace algorithm. The raytrace algorithm will in turn provide a range and height value which may be used within any TESS (3) CSCI which employs a raytrace algorithm.

4.3 Operator and User Interaction

EM system, environmental data, and maximum tracing range and height are specified by the operator. The output is an EM wave's position defined by a numeric couplet of range and height.

4.4 Computer System Characteristics

Not applicable.

5.0 GOVERNMENT AGENCIES

The Naval Ocean Systems Center developed the software and documentation for the raytrace technique. The Space and Naval Warfare Systems Command (PMW-141) manages the software development effort for TESS (3) with the Naval Oceanographic and Atmospheric Research Laboratory, Western Division acting as Technical Direction Agent. The Naval Electronic Systems Engineering Center Vallejo is the TESS (3)

Software Support Activity, In-Service Engineering Agent, and Life-Cycle Support Activity: The U.S. Navy is the user agency.

SOFTWARE REQUIREMENTS SPECIFICATION

FOR THE

RAYTRACE TECHNIQUE FOR A LATERALLY

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30 September 1990

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1.0 SCOPE

1.1 Identif.c tion

A raytrace technique for a laterally heterogeneous environment.

1.2 CSCI Overview

Electromagnetic (EM) wave propagation is the transmission of an EM wave between a transmitter and a receiver. If a particular point on the wave front is followed over time, the collection of point positions would define a ray. The ray would coincide with a line from the transmitter to the receiver, as illustrated in figure 1.2-1. The purpose of this CSCI is to describe an EM wave's path in terms of rays, as the wave propagates through a laterally heterogeneous medium where the index of refraction is allowed to vary both vertically and horizontally.

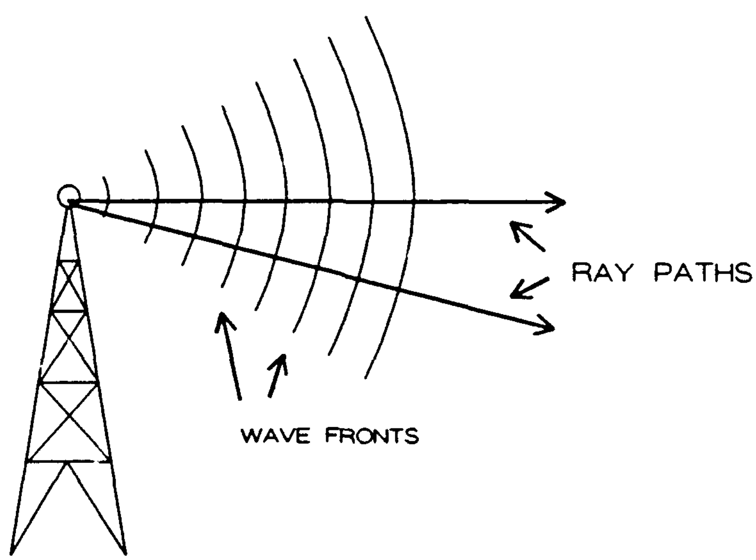

Figure 1.2-1. EM wave front and ray relationship.

1.3 Document Overview

This document specifies the software engineering and qualifications requirements for the laterally heterogeneous environment raytrace technique. Input/output software requirements are specified elsewhere in the TESS documentation.

2.0 REFERENCE DOCUMENTS

2.1 Government Documents

(a) Commander-In-Chief, Pacific Fleet Meteorological Requirement (PAC MET) 87-04, "Range Dependent Electromagnetic Propagation Models."

(b) Naval Oceanographic Office, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," Sep. 1988

(c) Naval Ocean Systems Center (NOSC) Technical Report 1180, "A Raytrace Method for a Laterally Heterogeneous Environment," Jul. 1987.

2.2 Non-Government Documents

Not applicable.

3.0 ENGINEERING REQUIREMENTS

3.1 CSCI External Interface Requirements

EM system, environmental data, and maximum tracing range and height are provided from a calling TESS CSCI. The raytrace CSCI is accessed to obtain a ray position defined by a numeric couplet of range and height. The output is routed to the calling TESS CSCI.

3.2 CSCI Capability Requirements

The purpose of this capability is to determine a ray position, defined by a height and range value, as an EM wave propagates through an atmosphere of pre-defined vertical segments and horizontally oriented layers. This CSCI may be divided into five constituents: one to Initialize necessary constants (Init); one to transition the ray between vertical atmospheric boundaries as determined by the various environmental profiles (Transprofile); one to transition the ray within a horizontally oriented atmospheric layer as determined by the M-unit gradients of two adjacent profiles (Intralayer); one to transition the ray across horizontally oriented atmospheric layer boundaries (Translayer); and one to compute a M-unit gradient at a given height and range (Mgrad).

3.2.1 Init Constituent

The purpose of this capability is to calculate various constants used by the raytrace CSCI. These constants are determined from inputs as specified within table 3.4-1.

3.2.2 Transprofile Constituent

The purpose of this constituent is to determine a ray's initial range, height, and angle of travel (relative to the local horizontal); to determine the raytrace range step size; and check for raytrace termination limits. These data elements are determined from inputs as specified within table 3.4-2.

3.2.3 Intralayer Constituent

The purpose of this constituent is to calculate a range, height, angle, and modified refractivity gradient at an intermediate point between the beginning range and the termination range. These data elements are determined from inputs as specified within table 3.4-3.

3.2.4 Translayer constituent

The purpose of this constituent is to calculate a range, height, angle, and modified refractivity gradient at a ray/environmental boundary intercept point. These data elements are determined from inputs as specified within table 3.4-4.

3.2.5 Mgrad Constituent

The purpose of this constituent is to calculate a M-unit gradient at a given height and range. This data element is determined from inputs as specified within table 3.4-5.

3.3 CSCI Internal Interfaces

The following steps are taken in the execution of the raytrace technique. Figure 3.3-1 illustrates the internal flow of the raytrace technique and figure 3.3-2 illustrates the definition of terms used.

a. Using the Init constituent of the raytrace CSCI, determine layer boundary slopes corresponding to each height data point within the environmental input profiles.

b. Using the Transprofile constituent of the raytrace CSCI, establish a beginning range, (x_0), of zero; a beginning height, (z_0), equal to the antenna height; and a beginning angle, (α_0), equal to the calling TESS CSCI input.

c. Using the Intralayer constituent of the raytrace CSCI

(1) Call the Mgrad CSC to determine a modified refractivity gradient ($\Delta M/\Delta z$) at the beginning point (x_0, z_0).

(2) Compute an ending height, (z_1), and angle, (α_1), by using as an ending range (x_1), the starting range (x_0) plus an increment, (Δx), equal to the range between two adjacent profiles divided by a resolution factor determined by the calling TESS CSCI's application.

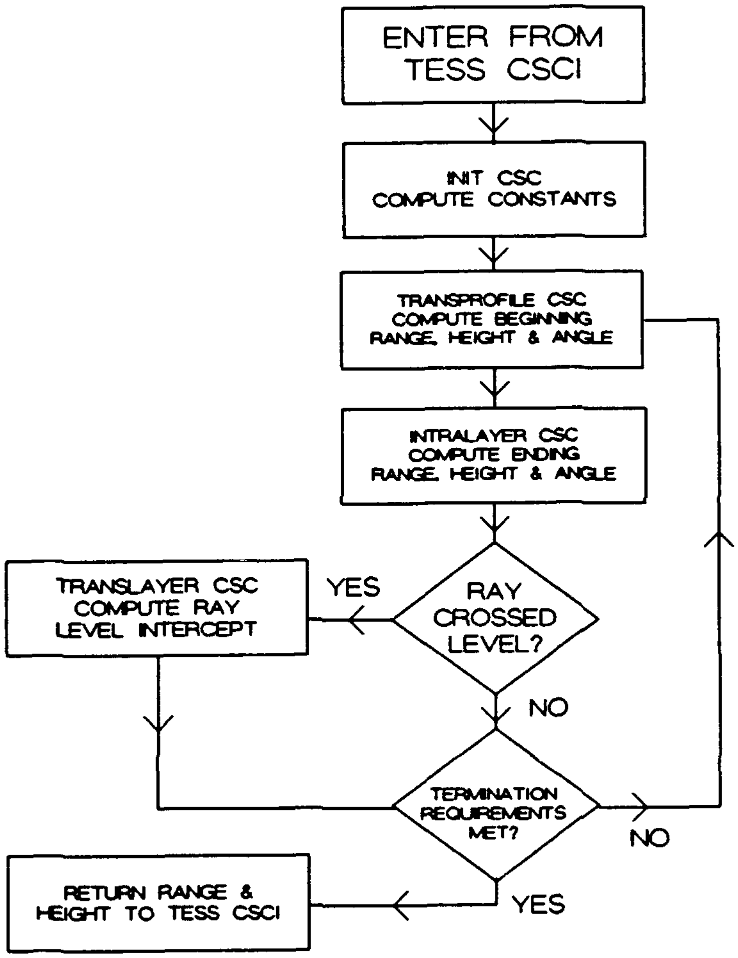

Figure 3.3-1. Program flow of the raytrace technique.

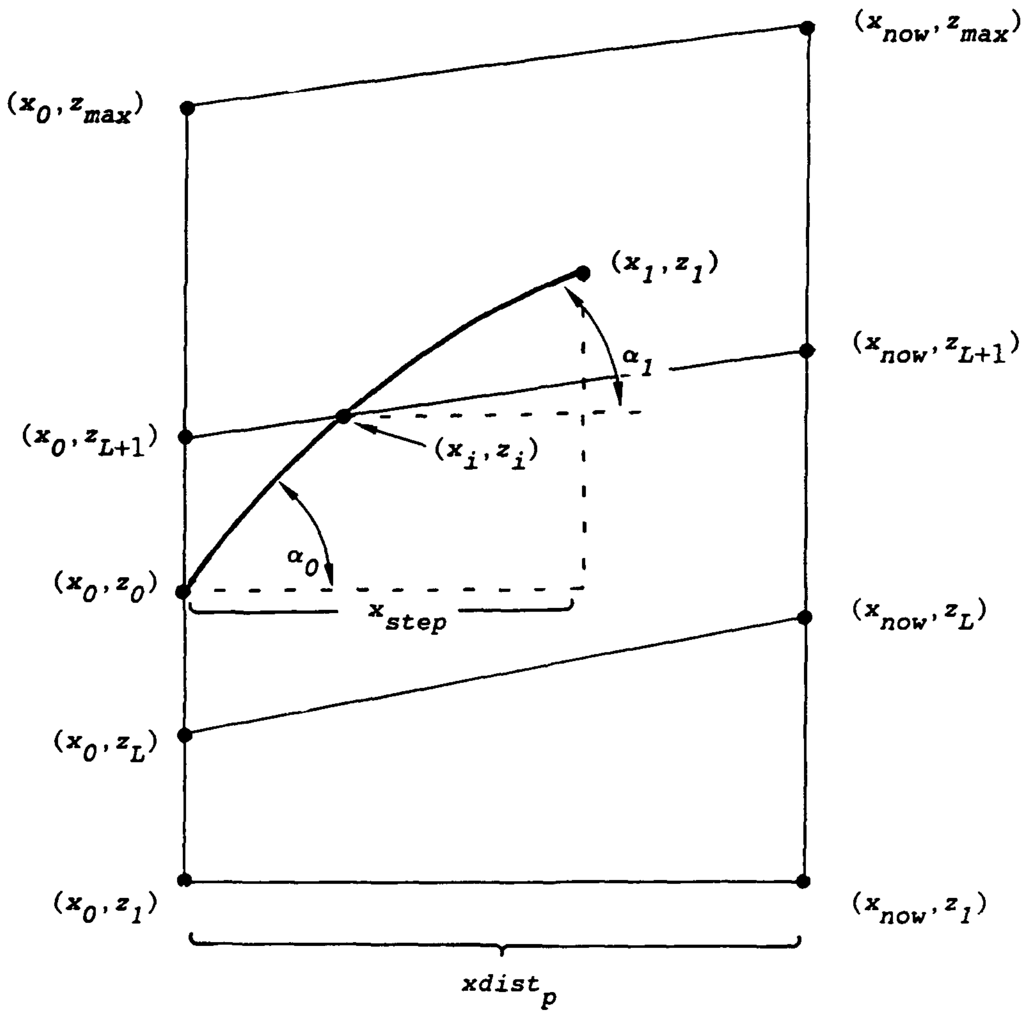

Figure 3.2-2. Definitions of terms used within the raytrace technique.

In subsequent range steps, the ending range must be compared to an intermediate tracing range, x_{now}, the range from the first to the pth profile. If the ending range exceeds the range between profiles, x_{dist}, the ending range is set to this intermediate tracing range and a new ending height and angle are computed.

(3) The ending angle is now examined. If it shows a sign reversal from the starting angle, the ray has passed through a maximum or minimum point. Should this be the case, the ending angle is set to 0 and a range and height of the maximum or minimum is computed. Again, the ending range must be compared to the intermediate tracing range between profiles as in step d above and, if necessary, readjusted with a new ending height and angle computed.

(4) At the ending range, the layer's upper and lower boundary heights are computed and compared to the ending height. If the ending height is outside the layer, the range, (x_i) and height, (z_i) of the ray/boundary intercept is computed with the Translayer constituent.

(5) Examine the ending height (z_i). If it is 0, the ray has reached the ground. In this case, the sign of the ending angle is reversed to indicate a surface reflection.

d. Using the Transprofile constituent of the raytrace CSCI, reInitialize the beginning range, height, and angle with the ending range, height, and angle; and step "c," 1 through 5, are repeated. This process continues until either the ray has reached the maximum propagation range or the maximum propagation height. At that time, the ending range and height are returned to the calling TESS CSCI.

3.4 CSCI Data Element Requirements

The following tables describe the global data elements within the raytrace CSCI. Table 3.4-1 specifies the data elements used by the Init CSC and lists the bounds of each data element, all of which are provided by the calling TESS CSCI.

Tables 3.4-2 through 3.4-6 specify the data elements used by the Init CSC, Transprofile CSC, Intralayer CSC, Translayer CSC, and Mgrad CSC respectively. Within each table the CSC where the data element is calculated is listed.

Table 3.4-1. RTT CSCI data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit.

Name	Description	Data Type	Units	Bounds
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	1 to 5,000
z	and height	real	m	0 to 30,000
f_{res}	Range step resolution factor	real	N/A	> 0
pnumbr	Number of profiles	integer	N/A	≥ 1[a]
lnumbr	Number of profile levels	integer	N/A	≥ 2
$xdist_p$	Range from 1st to *p*th profile	real	km	0 to 1,000[b]
z_{tran}	Antenna height	real	m	1 to 30,00[c]
α_{start}	Ray Initial launch angle	real	radians	-0.7853940 to 0.7853940

[a] If only one profile is available, it is input twice in order to define horizontally oriented layers. For the single profile case, the atmosphere would be homogeneous and the raytrace would not be range dependent.

[b] Maximum limit for practical purposes. In theory, unlimited.

[c] Maximum limit not to exceed the maximum height within a profile.

Specification of the radio-refractivity field, i.e., the profiles of M-units versus height, requires special consideration. The following requirements must be met.

The radio-refractivity field will consist of vertical piecewise linear profiles specified by couplets of height in meters above sea level and modified refractivity (M-units) at multiple arbitrary ranges. All vertical profiles must contain the same number of vertical data points and be specified such that each numbered data point corresponds to like-numbered points (i.e., features) in the other profiles. The first numbered data point of each profile must correspond to a height of zero and the last numbered data point must correspond to a height not less than the maximum height of the raytrace output. Within each profile, each numbered data point must correspond to a height level greater than or equal to the height at the previous data point. Note that a profile may contain redundant data points.

This specification allows a complicated refractivity field to be described with a minimum of data points. For example, a field in which a single trapping layer linearly descends with increasing range can be described with just two profiles containing only four data points each, frame (a) of figure 3.4-1. In the same manner, other evolutions of refractive layers may be described. Frames (b) and (c) of figure 3.4-1 show two possible scenarios for the development of a trapping layer. The scenario of choice is the one consistent with the true thermodynamical and hydrological layering of the atmosphere.

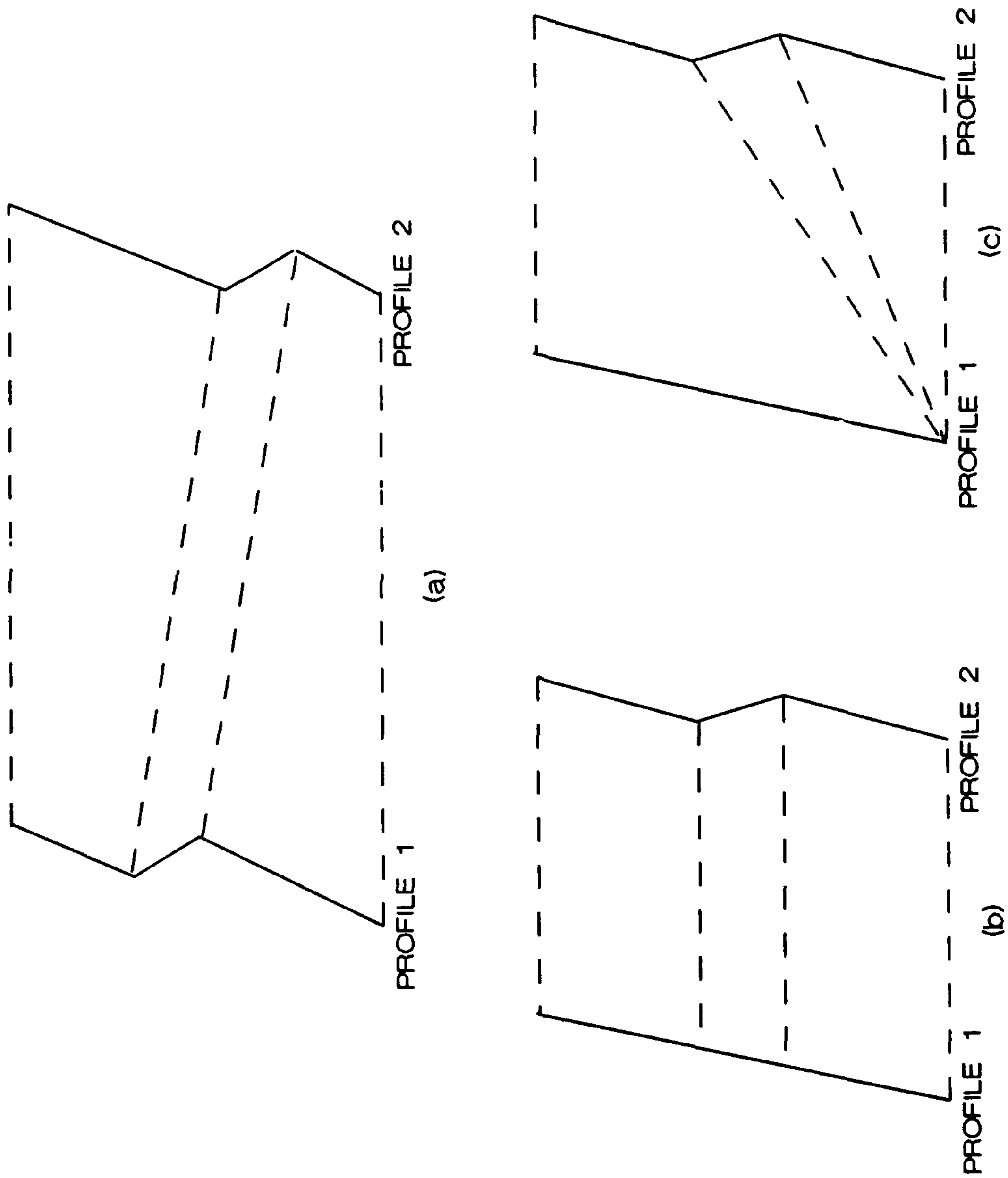

Figure 3.4-1. **Idealized M-unit profiles (solid lines) and lines of interpolation (dashed lines).**

Table 3.4-2. Init CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 3.4-1.

Name	Description	Data Type	Units	CSC Source
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	TESS CSCI
z	and height	real	m	TESS CSCI
pnumbr	Number of profiles	integer	N/A	TESS CSCI
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to pth profile	real	km	TESS CSCI
z_{tran}	Antenna height	real	m	TESS CSCI

Table 3.4-3. Transprofile CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 3.4-1.

Name	Description	Data Type	Units	CSC Source
f_{res}	Range step resolution factor	real	N/A	TESS CSCI
pnumbr	Number of profiles	integer	N/A	TESS CSCI
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
z_{tran}	Antenna height	real	m	TESS CSCI
α_{start}	Angle	real	radians	TESS CSCI
L_{tran}	Level number corresponding to the bottom boundary of the layer containing the antenna height.	integer	N/A	Init
x_{max}	Maximum propagation range	real	km	Init
z_{max}	Maximum propagation height	real	m	Init
L	Level counter	integer	N/A	Intralayer
α_1	Ending angle	real	radians	Intralayer
x_1	Ending range	real	km	Intralayer
z_1	Ending height	real	m	Intralayer

Table 3.4-4. Intralayer CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 3.4-1.

Name	Description	Data Type	Units	CSC Source
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
z_{max}	Maximum propagation height	real	m	Init
$\Delta z/\Delta x_{p,L}$	Layer boundary slope	real	m/km	Init
$\Delta M/\Delta z_{x_0,z_0}$	Local M-unit gradient	real	M/m	Mgrad
L	Level counter	integer	N/A	Transprofile
p	Profile counter	integer	N/A	Transprofile
x_0	Beginning range	real	km	Transprofile
z_0	Beginning height	real	m	Transprofile
α_0	Beginning angle	real	radians	Transprofile
x_{step}	Range step	real	km	Transprofile
x_{now}	Intermediate tracing range	real	km	Transprofile
L	Level counter	integer	N/A	Translayer
x_1	Ending range	real	km	Translayer
z_1	Ending height	real	m	Translayer
α_1	Ending angle	real	radians	Translayer

Table 3.4-5. Translayer CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 3.4-1.

Name	Description	Data Type	Units	CSC Source
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
$\Delta z/\Delta x_{p,L}$	Layer boundary slope	real	m/km	Init
α_0	Beginning angle	real	radians	Intralayer
α_1	Ending angle	real	radians	Intralayer
B_{x_0}	Layer bottom boundary height at beginning range	real	m	Intralayer
L	Level counter	integer	N/A	Intralayer
lyrflg	M-unit gradient flag	logical	N/A	Intralayer
p	Profile counter	integer	N/A	Intralayer
T_{x_0}	Layer top boundary height at beginning range	real	m	Intralayer
T_{x_1}	Layer top boundary height at ending range	real	m	Intralayer
x_1	Ending range	real	km	Intralayer
x_0	Beginning range	real	km	Intralayer
z_0	Beginning height	real	m	Intralayer
z_1	Ending height	real	m	Intralayer
$\Delta M/\Delta z_{x_0,z_0}$	Local M-unit gradient	real	M/m	Mgrad
x_{now}	Intermediate tracing range	real	km	Transprofile
x_{step}	Range step	real	km	Transprofile

Table 3.4-6. Mgrad CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 3.4-1.

Name	Description	Data Type	Units	CSC Source
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	TESS CSCI
z	and height	real	m	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
L	Level counter	integer	N/A	Intralayer
p	Profile counter	integer	N/A	Intralayer
x_0	Beginning range	real	km	Intralayer
x_{mid}	Range to midpoint of ray segment	real	km	Translayer

3.5 Security Requirements

Not applicable.

3.6 Design Constraints

Naval Oceanographic Office publication, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," applies. This CSCI shall be programmed in FORTRAN 77 with MIL-STD-1753 extension. For test and evaluation purposes, input/output is restricted to reading a text file for input data and writing data to a text file for output.

3.7 Human Performance/Human Engineering Requirements

Not applicable.

4.0 QUALIFICATION REQUIREMENTS

4.1 Qualification Techniques

This CSCI shall be qualified by analysis of test data generated under the Software Test Description.

4.2 Special Qualification Techniques

Not applicable.

SOFTWARE DESIGN DOCUMENT

FOR THE

RAYTRACE TECHNIQUE FOR A LATERALLY

HETEROGENEOUS ENVIRONMENT

30 September 1990

Prepared for:

Space and Naval Warfare Systems Command (PMW-141)

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FIGURES

TABLES

1.0 SCOPE

1.1 Identification

The raytrace technique for a laterally heterogeneous environment (RTT) is a computer software configuration item (CSCI) of the Tactical Environmental Support System (TESS). The operational concept document (OCD) and the software requirements specification (SRS) for the RTT contains the requirements from which the design of the RTT was derived.

1.2 Document Overview

The purpose of this document is to describe the design of the RTT CSCI in a detail sufficient for computer program coding in accordance with MIL-STD-1753. Naval Oceanographic Office publication, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," applies.

2.0 REFERENCE DOCUMENTS

(a) MIL-STD-1753 FORTRAN, DOD Supplement to American National Standard X3.9-1978.

(b) Naval Ocean Systems Center, "Operational Concept Document for the Raytrace Technique for a Laterally Heterogeneous Environment," Sep. 1990.

(c) Naval Ocean Systems Center, "Software Requirements Specification for the Raytrace Technique for a Laterally Heterogeneous Environment," Sep. 1990.

(d) Naval Ocean Systems Center, Technical Report 1180, "A Raytrace Method for a Laterally Heterogeneous Environment," Jul. 1987.

(e) Naval Oceanographic Office, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," Sep. 1988.

3.0 **PRELIMINARY DESIGN**

3.1 CSCI Overview

Electromagnetic (EM) wave propagation is the transmission of an EM wave between a transmitter and a receiver. If a particular point on the wave front is followed over time, the collection of point positions would define a ray. The ray would coincide with a line from the transmitter to the receiver, as illustrated in figure 3.1-1.

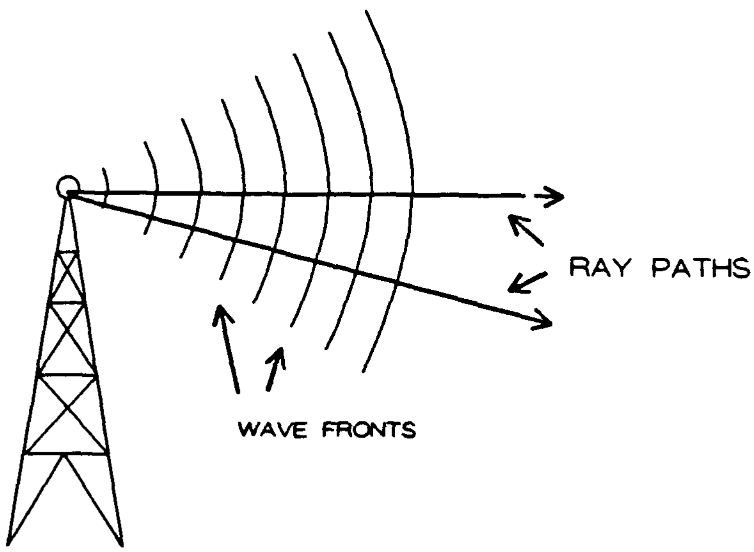

Figure 3.1-1. EM wave front and ray relationship.

The purpose of the RTT is to determine an EM wave's position, defined by a range and a height relative to a starting position; and a propagation direction, defined by an angle relative to the local horizontal, as the EM wave propagates through an atmosphere of pre-defined vertical segments and horizontally oriented layers. Outputs of range, height, and angle are routed to the TESS calling routine.

3.1.1 CSCI Architecture

The CSCI is composed of five computer software components (CSC): one to initialize necessary constants (Init); one to Transition the ray between vertical atmospheric boundaries as determined by the various environmental profiles (Transprofile); one to propagate the wave front within a horizontally oriented atmospheric layer as determined by the M-unit gradients of two adjacent profiles (Intralayer); one to Transition the wave front across horizontally oriented atmospheric layer boundaries (Translayer); and one to determine the M-unit gradient at a local range and height (Mgrad).

3.2 CSCI Design Description

3.2.1 Init

The Init CSC is accessed by a subroutine call from the TESS CSCI. The purpose of this CSC is to calculate various constants used by the four other CSCs of the RTT CSCI. A complete description of necessary inputs for the RTT is specifed in table 5.0-1 and a description of necessary inputs for the Init CSC is specified in table 5.0-2. A detailed discussion of environmental inputs is given by NOSC "Software Requirements Specification for the Raytrace Technique for a Laterally Heterogeneous Environment." The Init CSC program flow is as follows.

Calculations of maximum raytrace range and height based upon the environmental input parameters and layer boundary slopes for each horizontally oriented layer as defined by adjacent profiles are made.

The level number corresponding to the bottom boundary of the environmental layer containing the antenna height is determined.

Program flow is then passed to the Transprofile CSC.

3.2.2 Transprofile

The Transprofile CSC is accessed by a subroutine call from the Init CSC. The purpose of the Transprofile CSC is to establish a ray segment's beginning range, height, and angle and to compare outputs from the Intralayer CSC with program termination requirements. A complete description of necessary inputs are specified in table 5.0-3. The Translayer CSC program flow is as follows.

A ray's beginning range, height, and angle are initialized with zero, antenna height, and input starting angle respectively.

An intermediate tracing range is established as the range between the first two environmental profiles, and a raytrace range step is calculated as an increment of the intermediate tracing range. An environmental profile counter and a level counter are initialized.

Control is passed to the Intralayer CSC for computation of the ray segment's ending range, height, and angle.

The ray segment's ending range and height are compared to the maximum tracing range and height. If the maximum tracing range or height is exceeded, control is returned to the calling TESS CSCI. If the maximum tracing range or height have not been exceeded however, the profile counter, intermediate tracing range, range step size, and the ray segment's beginning range, height, and angle are reinitialized and control is returned to the Intralayer CSC.

3.2.3 Intralayer

The Intralayer CSC is accessed by a subroutine call from the Transprofile CSC. The purpose of the Intralayer CSC is to calculate a ray segment's ending range, height, and angle within a horizontally oriented environment layer. A complete description of necessary

inputs are specified in table 5.0-4. The Intralayer CSC program flow is as follows.

From a subroutine call to the Mgrad CSC, an M-unit gradient at the ray segment's starting range and height is obtained. Calculations of the layer's horizontal boundaries heights are made at the starting range.

The ray segment's ending range is calculated. If the ray segment's ending range has exceeded the intermediate tracing range, it is reset to the intermediate tracing range. The heights of the layer's horizontal boundaries are calculated at this ending range.

The ray segment's ending height and angle are computed. The ending height is examined to determine if the ray has penetrated either of the layer's horizontal boundaries. If so, control is passed to the Translayer CSC for a calculation of the ray segment/boundary intercept range, height, and angle.

Control is then returned to the Transprofile CSC.

3.2.4 Translayer.

The Translayer CSC is accessed by a subroutine call from the Intralayer CSC. The purpose of the Translayer CSC is to calculate a range, height, and angle at a ray segment/environmental boundary intercept point. A complete description of necessary inputs are specified in table 5.0-5. The Translayer CSC program flow is as follows

The ray segment's ending height is examined to determine which of the layer's boundaries, top or bottom, has been penetrated.

The ray segment/boundary intercept range is computed, using either a quadratic solution to a parabolic ray-path as would occur in a refractive (non-zero M-unit gradient) layer, or an oblique triangle solution to a straight-line ray-path as would occur in a non-refractive (zero M-unit gradient) layer. If the intercept range

exceeds the intermediate tracing range, it is reset to the intermediate tracing range.

An intercept height is computed using again, the quadratic or oblique triangle method as appropriate.

An intercept angle is computed from traditional raytrace equations for the case of a refractive layer or is set to the beginning angle for the case of a non-refractive layer.

Finally, if the layer's bottom boundary has been penetrated, the level counter is incremented and then control is returned to the Intralayer CSC.

3.2.5 Mgrad

The Mgrad CSC is accessed by a subroutine call from the Intralayer CSC. The purpose of the Mgrad CSC is to calculate an M-unit gradient at a local range and height. A complete description of necessary inputs are specified in table 5.0-6. The Mgrad CSC program flow is as follows.

Compute a ratio proportionality factor which is used in linear interpolations of height and M-units.

At the local range, interpolate between adjacent profiles to determine the upper and lower boundary heights for the atmospheric layer under consideration.

Due to the specification of atmospheric layers as presented in Naval Ocean Systems Center, "Software Requirements Specification for the Raytrace Technique for a Laterally Heterogeneous Environment," an atmospheric layer may be artificial, i.e., the upper and lower boundary heights are equal; or the layer may be real, i.e., the upper and lower boundary heights are unequal. The RTT also allows for real layers to have an M-unit gradient of zero. In this case, there is no refraction and the ray path is a straight line.

If the boundary heights are equal, the level counter is recursively incremented downward with the boundary heights recalculated until they are no longer equal or until the ground is reached.

The M-unit gradient at the local range and height is then interpolated between adjacent profiles and control is returned to the calling Intralayer CSC.

4.0 DETAILED DESIGN

4.1 CSC Init

The RTT is accessed, through the Init CSC, by a subroutine call from the TESS CSCI which provides, as global data elements, the values specified in table 5.0-1. Figure 4.1-1 illustrates the program flow of the Init CSC, and figure 4.1-2 illustrates the definition of terms used by this CSC.

Upon entering the Init CSC, the following variables are computed and provided to the other four RTT CSCs as global data elements.

(1) Maximum raytrace range and height,

$$x_{max} = xdist_{pnumbr} \quad \text{(km)}, \tag{1}$$

$$z_{max} = z_{1,lnumbr} \quad \text{(m)}, \tag{2}$$

where $pnumbr$ is the number of environmental profiles, $xdist_{pnumbr}$ is the distance from 0 to the last (furthest) profile, $lnumbr$ is the number of levels within any profile (each profile must have the same number of levels), and $z_{1,lnumbr}$ is the maximum height within the first profile (the maximum height must be the same for all profiles).

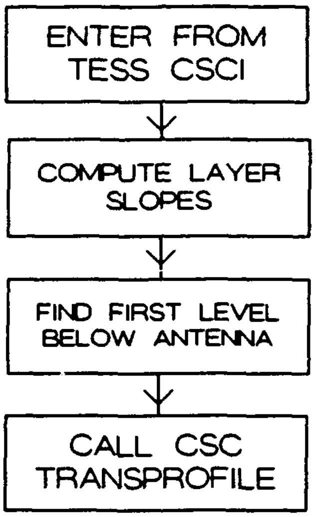

Figure 4.1-1. Program flow of the Init CSC.

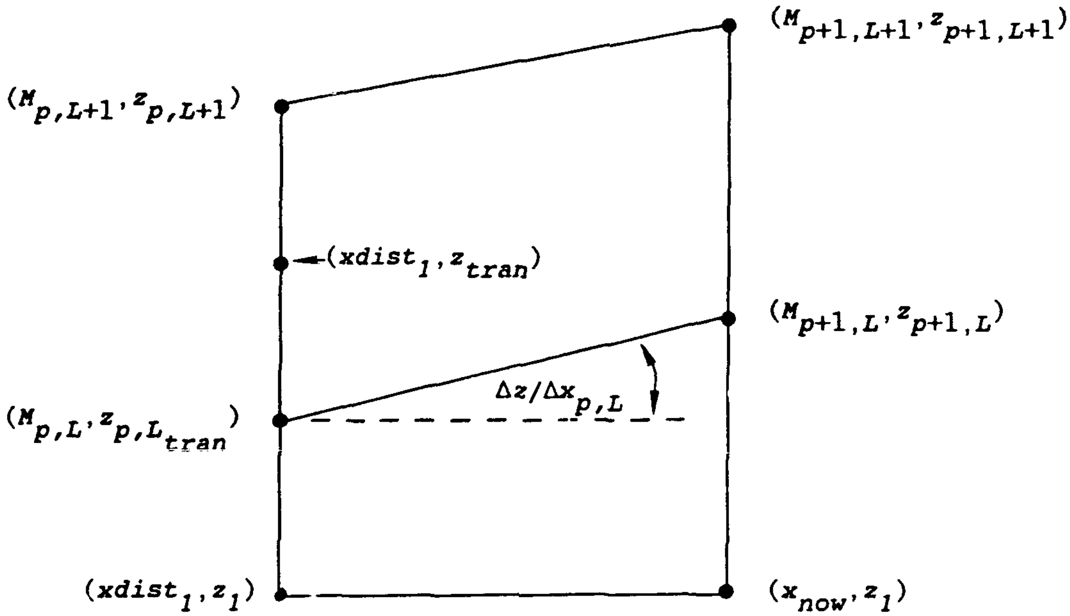

Figure 4.1-2. Definition of terms used by the Init CSC.

(2) Layer slopes for each horizontally oriented layer as defined by adjacent profiles,

$$\Delta z/\Delta x_{p,L} = \frac{(z_{p,L+1} - z_{p,L})}{xdist_{p+1} - xdist_p} \quad (\text{m/km}) \quad , \qquad (3)$$

where $z_{p,L+1}$ and $z_{p,L}$ are consecutive level heights within the pth profile and $xdist$ is the range between the two adjacent profiles.

(3) The level number corresponding to the bottom boundary of the layer containing the antenna height, i.e.,

$$L_{tran} = L \quad \text{such that} \quad z_L < z_{tran} < z_{L+1} \quad , \qquad (4)$$

where z_{tran} is the antenna height and L is a level counter.

Upon completion of the constant initialization, the Transprofile CSC is called.

4.2 CSC Transprofile

The Transrofile CSC is accessed by a subroutine call from the Init CSC. Inputs to the Transprofile CSC provided by the Init CSC, the Intralayer CSC, and the calling TESS CSCI are specified in table 5.0-3. Figure 4.2-1 illustrates the program flow of the Transprofile CSC, and figure 4.2-2 illustrates the definition of terms used by this CSC.

Upon entering the Transprofile CSC, the following variables are initialized:

(1) The profile counter is set to

$$p = 1 \qquad (5)$$

(2) The level counter is set to

$$L = L_{tran} \qquad (6)$$

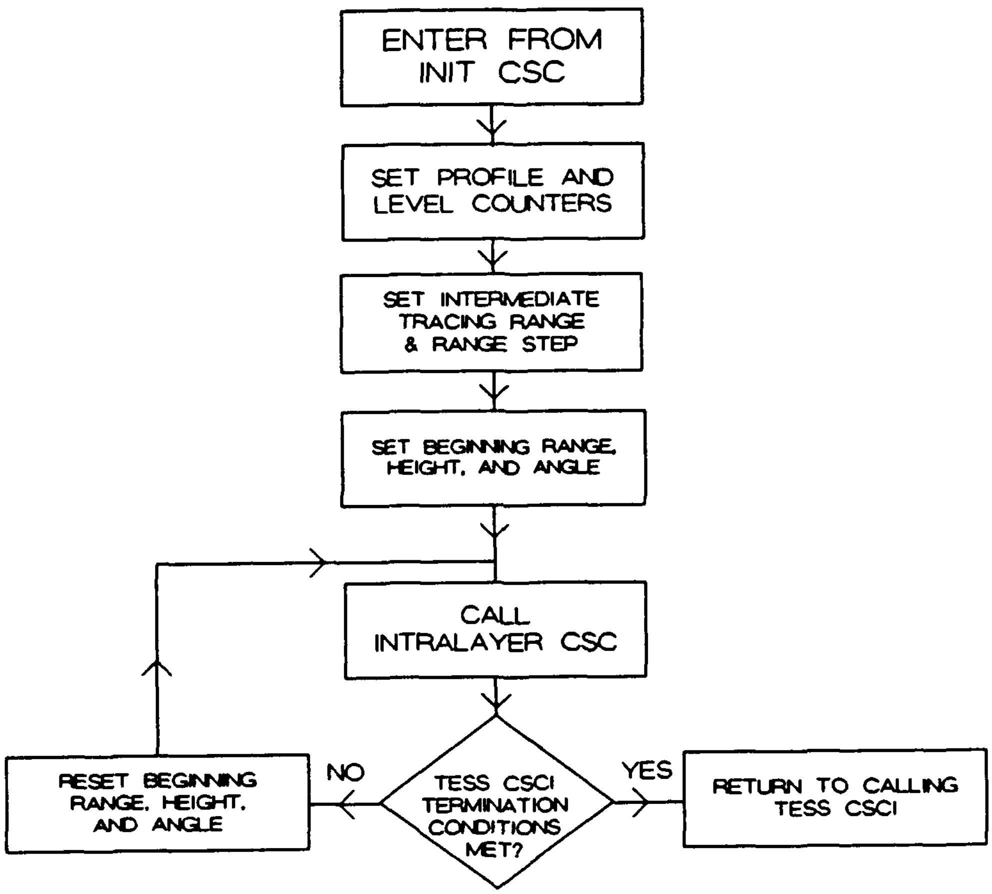

Figure 4.2-1. Program flow of the Transprofile CSC.

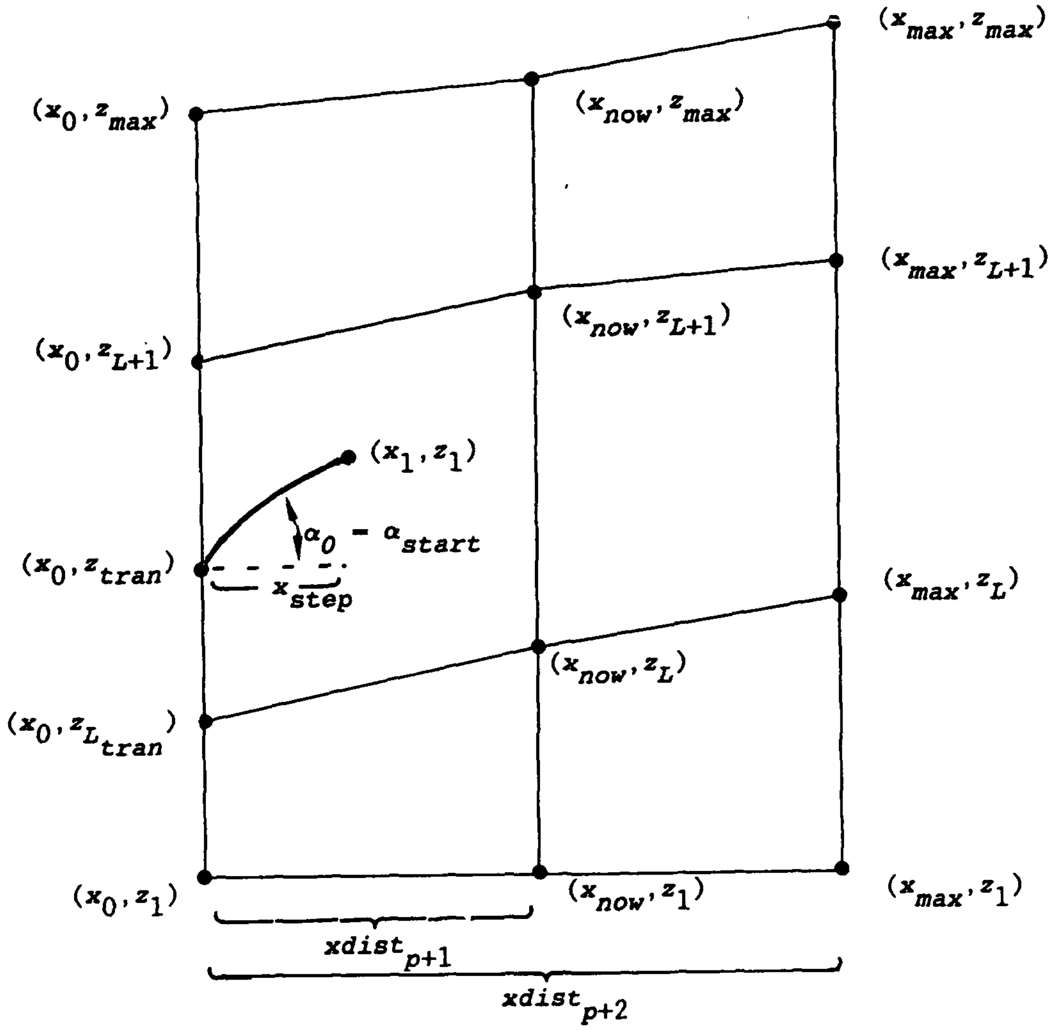

Figure 4.2-2. Definition of terms used by the Transprofile CSC.

(3) The initial range is set to

$$x_0 = xdist_1 = 0.0 \qquad \text{(km)} \qquad (7)$$

(4) The intermediate tracing range is set to

$$x_{now} = xdist_{p+1} \qquad \text{(km)} \qquad (8)$$

where $xdist_{p+1}$ is the range from the first profile (0 kilometers) to the second profile.

(5) The initial height is set to

$$z_0 = z_{tran} \qquad \text{(m)} \qquad (9)$$

(6) The range step is set to

$$x_{step} = x_{now} / f_{res} \qquad \text{(km)} \quad , \quad (10)$$

where the resolution factor, f_{res}, is determined by the CSCI application, and

(7) The initial angle is set to

$$\alpha_0 = \alpha_{start} \qquad \text{(radians)}. \quad (11)$$

After the initial variable assignments have been made, the following steps are recursively performed until the maximum propagation range has been reached, $x_0 = x_{max}$, the maximum propagation height has been reached, $z_0 = z_{max}$, or until the level counte has exceeded the number of levels within the profile, $L \geq lnumbr$. Upon meeting any of these conditions, control is returned to the calling TESS CSCI.

(1) Access the Intralayer CSC for the calculation of an ending range, x_1; an ending height, z_1; an ending angle, α_1; and a level counter, L.

(2) Reinitialize the beginning range, height, and angle as

$$x_0 = x_1 \qquad \text{(km)} \quad , \qquad (12)$$

$$z_0 = z_1 \qquad \text{(m)} \quad , \qquad (13)$$

and

$$\alpha_0 = \alpha_1 \qquad \text{(radians)}. \qquad (14)$$

(3) Examine the beginning range. If the intermediate tracing range has been reached, $x_0 \geq x_{now}$, but the maximum propagation range has not, $x_0 < x_{max}$, increment the profile counter, $p = p + 1$, increment the intermediate tracing range as

$$x_{now} = xdist_{p+1} - xdist_p \qquad \text{(km)} \; , \qquad (15)$$

and recompute the range step using equation 10.

4.3 <u>CSC Intralayer</u>

The Intralayer CSC is accessed by a subroutine call from the Transprofile CSC. Inputs to the Intralayer CSC provided by the Init CSC, the Transprofile CSC, the Translayer CSC, and the calling TESS CSCI are specified in table 5.0-4.

Figure 4.3-1 illustrates the program flow of the Intralayer CSC which will, given a starting range, height and angle, compute an ending range, height, and angle. In addition, if the ray-path penetrates a layer's horizontally oriented boundary, the Translayer CSC will be accessed to compute the ray/boundary intercept point. Figure 4.3-2 illustrates the definition of terms used by this CSC.

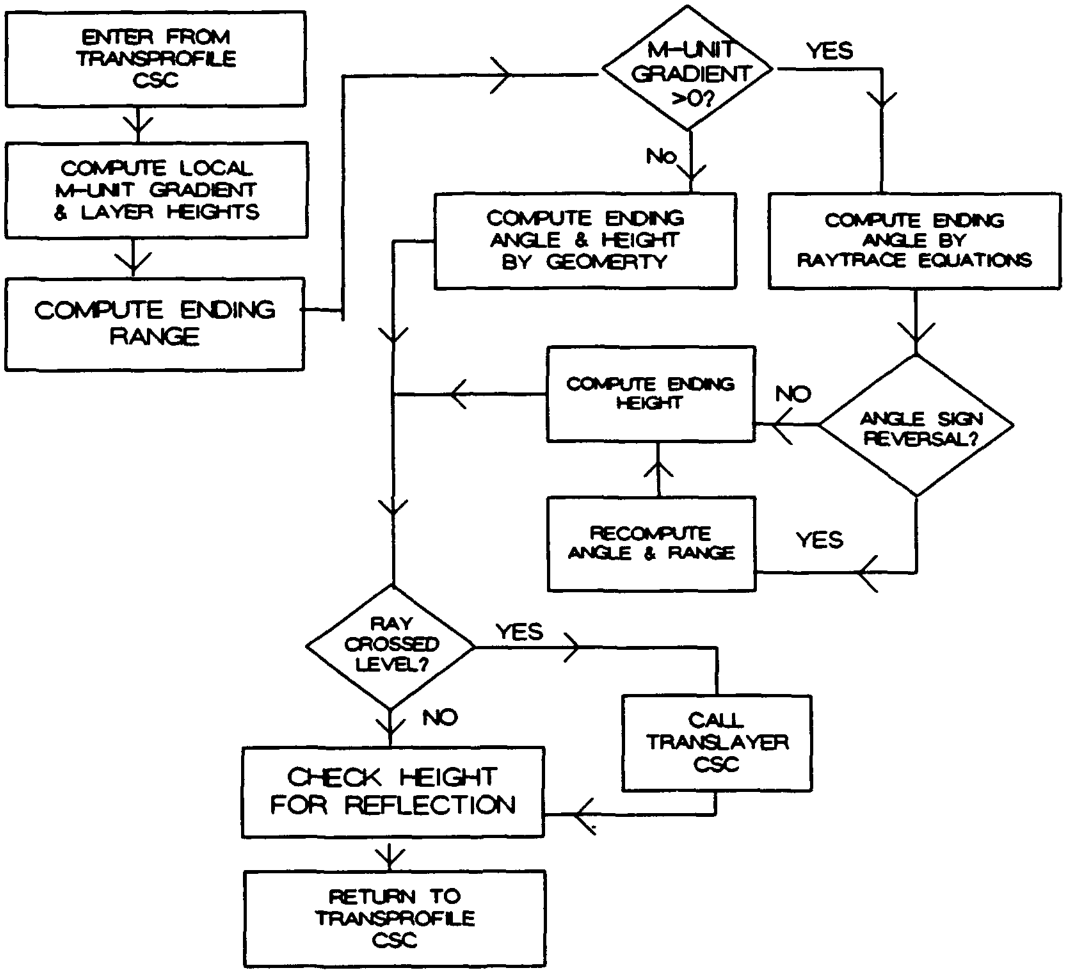

Figure 4.3-1. Program flow of the Intralayer CSC.

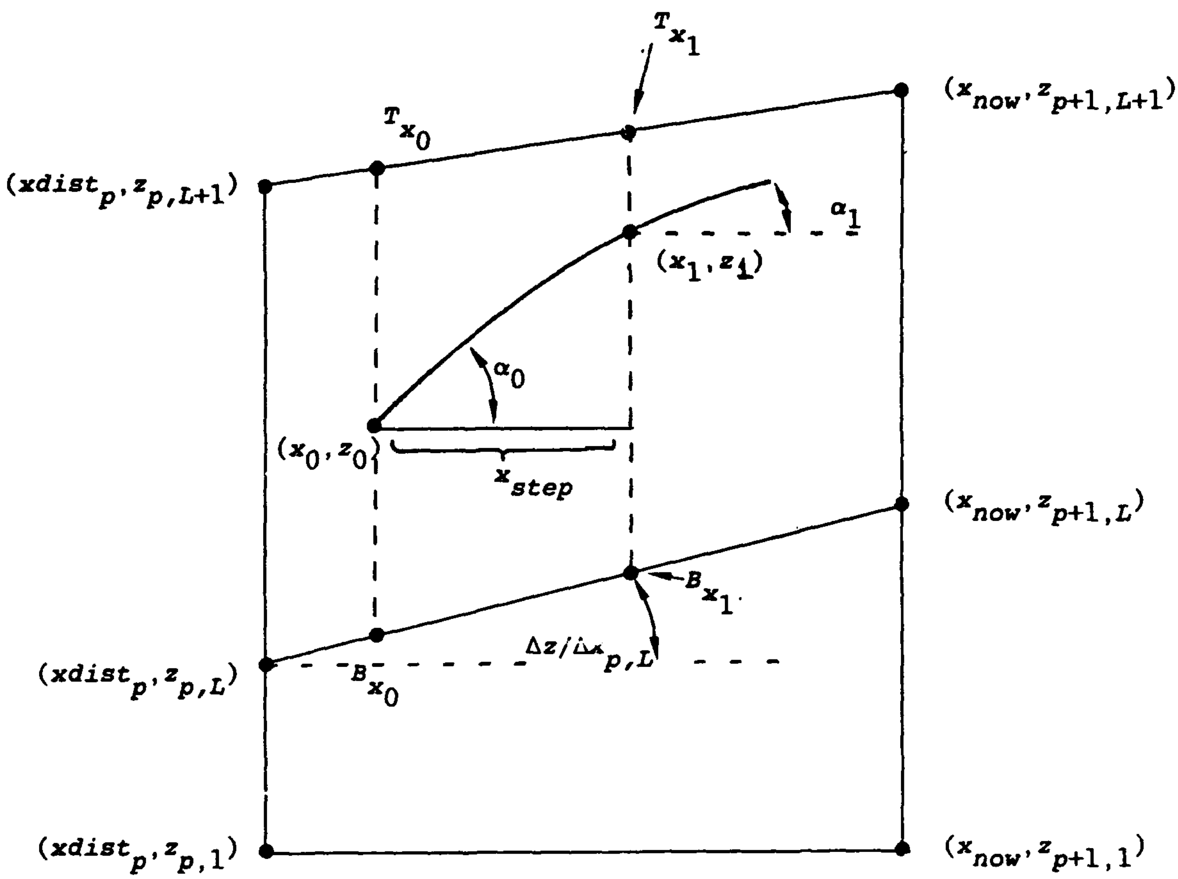

Figure 4.3-2. Definition of terms used by the Intralayer CSC.

Upon entering the Intralayer CSC, a subroutine call to the Mgrad CSC is made for the local M-unit gradient at the starting range and height. The top and bottom boundaries of the atmospheric layer under consideration are calculated. These are

(1) Layer bottom at the ray segment's starting range

$$B_{x_0} = \Delta z/\Delta x_{p,L} \, (x_0 - xdist_p) + z_{p,L} \quad \text{(m)} \; , \qquad (16)$$

(2) Layer top at the ray segment's starting range

$$T_{x_0} = \Delta z/\Delta x_{p,L+1} \, (x_0 - xdist_p) + z_{p,L+1} \; \text{(m)} \; , \qquad (17)$$

where L is the level counter and p is the profile counter.

Once the layer boundaries have been computed, an ending range is calculated as

$$x_1 = x_0 + x_{step} \qquad \text{(km)} \quad . \qquad (18)$$

The ending range is now compared to the intermediate tracing range (x_{now}). If the intermediate tracing range has been exceeded, the ending range is reset as

$$x_1 = x_{now} \qquad \text{(km)} \quad . \qquad (19)$$

For the case of a real layer where the local M-unit gradient is zero, there is no refraction of the ray and the ray-path is, therefore, a straight line. The ending angle is calculated using simple geometry as

$$\alpha_1 = \alpha_0 \qquad \text{(radians)} \qquad (20)$$

and the ending height as

$$z_1 = z_0 + \tan(\alpha_0) \; ((x_1 - x_0) \; 1000.0) \quad \text{(m)} \quad . \qquad (21)$$

For real levels with a nonzero M-unit gradient, the ending angle is calculated using the traditional raytrace equation of

$$\alpha_1 = \alpha_0 + \Delta M/\Delta z_{x_0, z_0}(x_1 - x_0) \quad \text{(radians)} . \qquad (22)$$

The refracted ray may have passed through an inflection point and the ending angle will, therefore, have a sign reversal from the starting angle. In this case, the ending angle is set to

$$\alpha_1 = 0. \qquad \text{(radians)} \qquad (23)$$

and the range to this inflection point is computed as

$$x_1 = x_0 - \frac{\alpha_0}{\Delta M/\Delta z_{x_0,\ z_0}} \qquad \text{(km)} \quad , \qquad (24)$$

and the ending height is given as

$$z_1 = z_0 + (\alpha_1^2 - \alpha_0^2) \ / \ (0.002 \ \Delta M/\Delta z_{x_0, z_0}) \quad \text{(m)} . \qquad (25)$$

Following the computation of the ending range, height, and angle, by either of the two above methods, the ending height must be examined to see if the ray has penetrated a layer boundary. If it has, the Translayer CSC is accessed to determine the ray/boundary intercept point. The technique for this examination is as follows.

First, the layer's bottom boundary at the ray's ending range is computed as

$$B_{x_1} = \Delta z/\Delta x_{p,L} \ (x_1 - xdist_p) + z_{p,L} \quad \text{(m)} , \qquad (26)$$

and the layer's top boundary at the ray's ending range is computed as

$$T_{x_1} = \Delta z/\Delta x_{p,L} \ (x_1 - xdist_p) + z_{p,L} \quad \text{(m)} , \qquad (27)$$

where L is the level counter and p is the profile counter.

The ending height, z_1, is now compared to the boundary heights. If $z_1 > T_{x_1}$ or $z_1 < B_{x_1}$ the ray has penetrated a boundary and the Translayer CSC is accessed to compute the ray/boundary intercept point.

Prior to accessing the Translayer CSC, a special circumstance must be examined. The ray's starting height may coincided with the layer's bottom boundary, $z_0 = B_{x_0}$, and the ray-path may be such that the ray enters the layer below, $z_1 < B_{x_1}$. In this case, the above computed range, height, and angle are accepted and the level counter is decreased by one in preparation for the next call to the Intralayer CSC. It may be, however, that the angle of penetration is sufficiently steep to have caused the ray to also penetrate this lower layer. To evaluate this possibility, the lower layer's bottom boundary is computed using equation 26 and the now reduced level counter; and if z_1 is also less that this new bottom boundary value, the Translayer CSC is accessed to compute the first ray/boundary intercept point.

Finally, the level counter is examined. IF it is less than or equal to zero, a surface reflection has occurred. The level counter is reset to one, the sign of the ending angle is reversed, and the ending height is set to zero.

Control is returned to the calling Transprofile CSC.

4.4 CSC Translayer

The Translayer CSC is accessed by a subroutine call from the Intralayer CSC. Inputs to the Translayer CSC provided by the Init CSC, the Transprofile CSC, the Intralayer CSC, and the calling TESS CSCI are specified in table 5.0-5.

Figure 4.4-1 illustrates the program flow of the Translayer CSC which will compute a range, height, and angle at a ray segment/boundary intercept point.

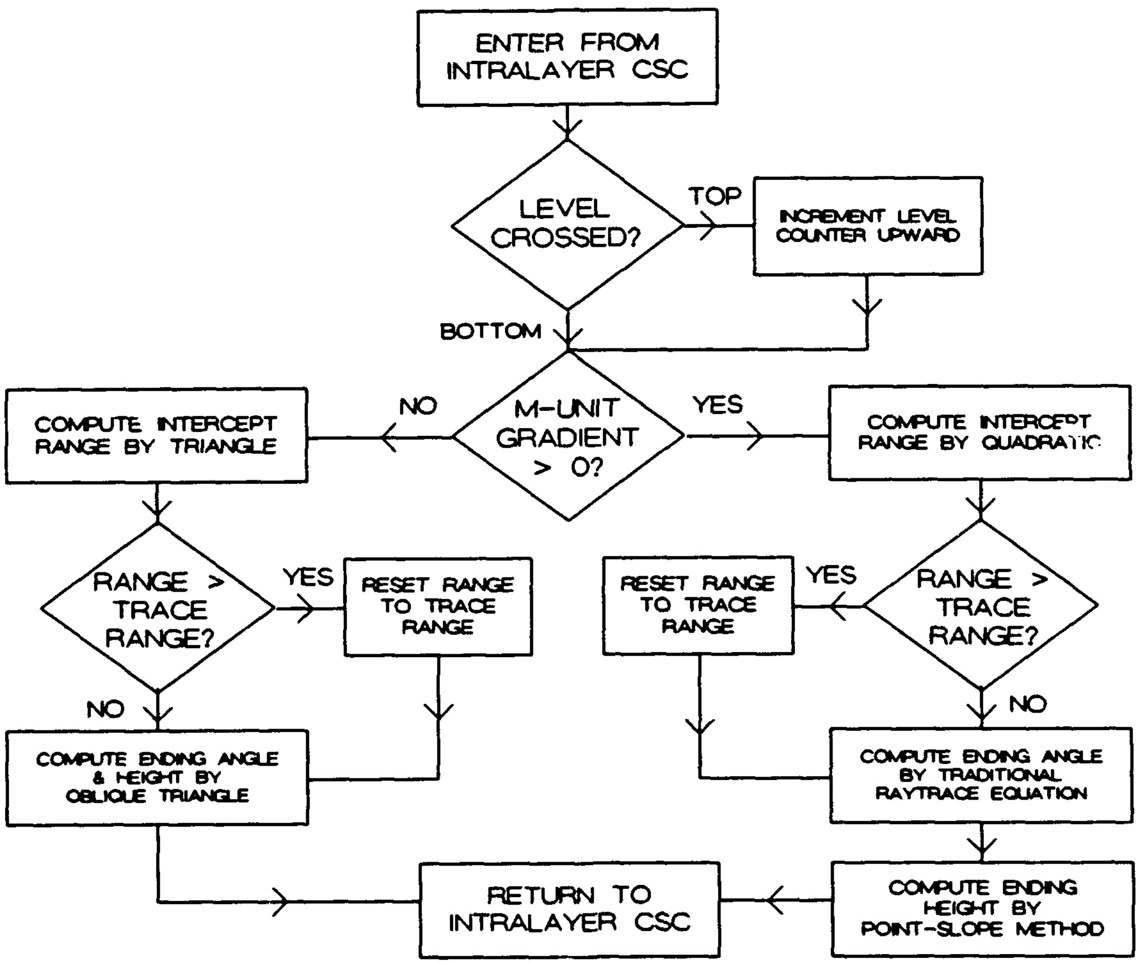

Figure 4.4-1. Program flow of the Translayer CSC.

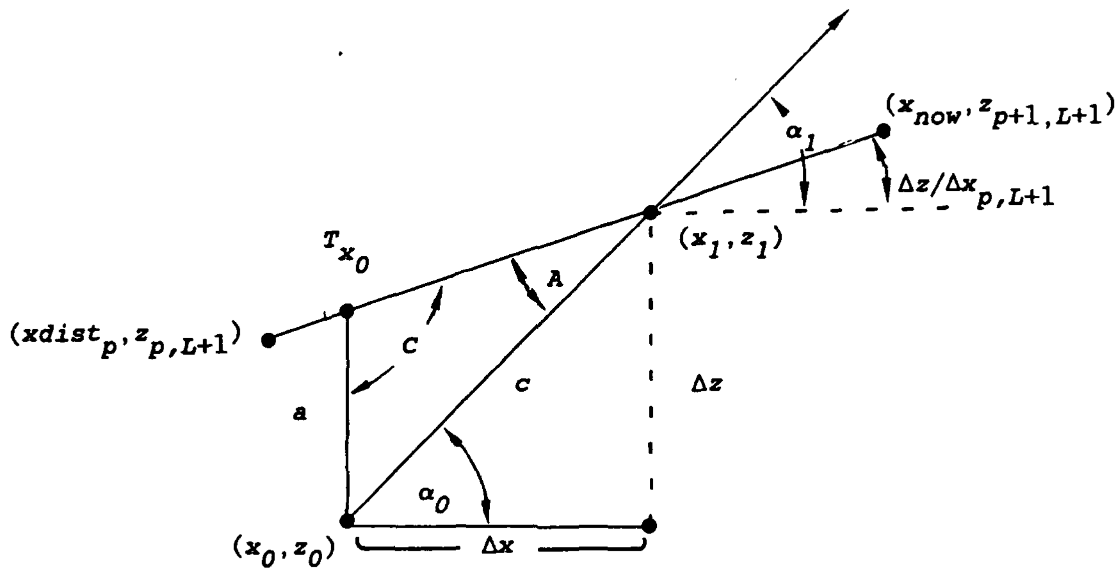

Figure 4.4-2. Definition of terms used by the geometric method of the Translayer CSC.

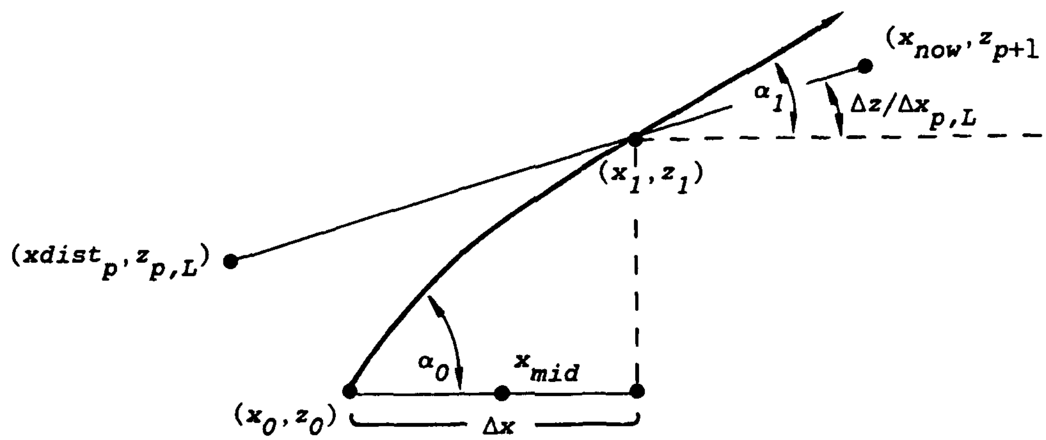

Figure 4.4-3. Definition of terms used by the parabolic method of the Translayer CSC.

Upon entering the Translayer CSC, the ending height and the height of the layer at the ending range are compared to determine which layer boundary, top or bottom, has been penetrated. If it is the top boundary, the level counter is incremented by one.

Continued processing within the Translayer CSC depends upon the M-unit gradient at the beginning range and height. If the M-unit gradient is zero, the ray is not refracted and the ray-path is therefore a straight line. In this case, the ending range, height, and angle are determined from simple triangle geometry as illustrated in figure 4.4-2.

For this zero M-unit gradient case, it is necessary to use the law of sines to solve an oblique triangle for an ending range. Side "*a*" of the triangle is computed by

$$a = T_{x_0} - z_0 \qquad \text{(m)} \qquad (28)$$

if the top boundary has been penetrated or by

$$a = z_0 - B_{x_0} \qquad \text{(m)} \qquad (29)$$

if the bottom boundary has been penetrated.

Based upon the relationship between the beginning angle, α_0, and the layer slope, $\Delta z/\Delta x_{p,L}$ / 1000., the two angles A and C of the triangle are given as

Case a: $|\alpha_0| > |\Delta z/\Delta x_{p,L}| / 1000.$ or $\Delta z/\Delta x_{p,L} = 0.$

$$A = |\alpha_0| - |\Delta z/\Delta x_{p,L}| / 1000. \qquad \text{(radians)}, \qquad (30)$$

and

$$C = 1.5707963 + |\Delta z/\Delta x_{p,L}| / 1000. \qquad \text{(radians)}. \qquad (31)$$

Case b: $|\alpha_0| < |\Delta z/\Delta x_{p,L}| / 1000.$ or $\alpha_0 = 0.$

$$A = |\Delta z/\Delta x_{p,L}| / 1000. - |\alpha_0| \qquad \text{(radians)}\ , \qquad (32)$$

and

$$C = 1.5707963 + |\alpha_0| \qquad \text{(radians)}\ . \qquad (33)$$

Side "c" is now given by

$$c = a \sin(C) / \sin(A) \qquad \text{(m)}\ . \qquad (34)$$

A new range increment is given by

$$\Delta x = (c \cos(|\alpha_0|)) / 1000.0 \qquad \text{(km)}\ , \qquad (35)$$

and the ending range is therefore

$$x_1 = x_0 + \Delta x \qquad \text{(km)}\ . \qquad (36)$$

The ending range is now compared to the intermediate tracing range. If the intermediate tracing range has been exceeded, the ending range is reset as

$$x_1 = x_{now} \qquad \text{(km)} \qquad (37)$$

and the ending height is calculated as

$$z_1 = z_0 + (x_1 - x_0)\ 1000.\ \tan(\alpha_0) \qquad \text{(m)}\ . \qquad (38)$$

If the intermediate tracing range has not been exceeded, the ending height is calculated as

$$z_1 = z_0 + c \sin(\alpha_0) \qquad \text{(m)}\ . \qquad (39)$$

Since the M-unit gradient is zero, the ray-path is a straight line and the ending angle is set as

$$\alpha_1 = \alpha_0 \qquad \text{(radians)} \ . \qquad (40)$$

If the M-unit gradient is not zero, the ray is undergoing refraction and a quadratic solution to a parabolic curve is used to determine the ending range, height, and angle. Figure 4.4-3 illustrates the definition of terms used by this parabolic technique.

The coefficients of the quadratic equation describing the ray-path parabola are

$$a = \Delta M/\Delta z_{x_0, z_0} / \ 0.002 \qquad , \qquad (41)$$

$$b = (2.0 \ \alpha_0 \ / \ 0.002) - \Delta z/\Delta x_{p,L} \qquad , \qquad (42)$$

and

$$c = z_0 - \Delta z/\Delta x_{p,L} \ (x_0 - xdist_p) - z_{p,L} \qquad (43)$$

where p is the profile counter and L is the level counter. The range increment is given by the standard quadratic formula

$$\Delta x = \frac{-b \pm (b^2 - 4ac)^{0.5}}{2a} \qquad (44)$$

using the formulation which produces a Δx such that $0.0 < \Delta x < x_{step}$. The ending range is computed by using equation 36. The ending range is now compared to the intermediate tracing range. If the intermediate tracing range has been exceeded, the ending range is reset to the intermediate tracing range as in equation 37. To insure that the M-unit gradient used for the ending

The ending angle is calculated using the traditional raytrace technique, equation 22. To insure that the M-unit gradient used within the ending angle calculation represents only the portion of the ray-path prior to exiting the layer (either vertically into another layer or horizontally beyond the next profile), the Mgrad CSC is

called to recalculate the local M-unit gradient. The ending height is than calculated as

$$z_1 = \Delta z/\Delta x_{p,L} \; (x_1 - xdist_p) + z_{p,L} \qquad \text{(m)} \qquad (45)$$

where p and L are the profile and level counters respectively.

Finally, if the bottom boundary is the one penetrated, the level counter is reduced by one. Control is then returned to the Intralayer CSC.

4.5 CSC Mgrad

The Mgrad CSC is accessed by a subroutine call from the Intralayer CSC. Inputs to the Mgrad CSC provided by the Intralayer CSC and the calling TESS CSCI are specified in table 5.0-6.

Figure 4.5-1 illustrates the program flow of the Mgrad CSC, and figure 4.5-2 illustrates the definition of terms used by this CSC.

Due to the specification of atmospheric layers as presented in Naval Ocean Systems Center, "Software Requirements Specification for the Raytrace Technique for a Laterally Heterogeneous Environment," an atmospheric layer may be artificial ($z_{p,L} = z_{p,L+1}$) or real ($z_{p,L} \neq z_{p,L+1}$). The RTT also allows for real layers to have an M-unit gradient of zero. In this case there is no refraction and the ray-path is a straight line.

Upon entering the Mgrad CSC, the layer's top ($z1$) and bottom ($z0$) boundary heights at the current range (x_0) are computed as

$$z0 = z_{p,L} + K \; (z_{p+1,L} - z_{p,L}) \qquad \text{(m)} \qquad (46)$$

and

$$z1 = z_{p,L+1} + K \; (z_{p+1,L+1} - z_{p,L+1}) \qquad \text{(m)} \qquad (47)$$

where p and L are the profile and level counters respectively, and K is a ratio proportionality factor given as

$$K = (x_{mid} - xdist_p) \;/\; (xdist_{p+1} - xdist_p) \;. \qquad (48)$$

Since the standard raytrace equations assume the M-unit gradient used is the average over the ray segment's length, the range x_{mid} is,

$x_0 + x_{step}/\ 2$ for a ray-path entirely within a layer;

$x_0 + (xdist_{p+1} - x_0)\ /2$ for a ray-path which exceeds x_{now};

or

$x_0 + \Delta x\ /\ 2$ for a ray-path which crosses a layer boundary.

These two boundary heights are then compared. If these heights are equal, the layer is artificial. The level counter is recursively incremented downward, recomputing the layer boundaries (equations 46 and 47) until the layer boundaries are no longer equal or until the ground is reached, i.e., $L = 1$.

Finally, the local M-unit gradient is then calculated as

$$\Delta M/\Delta z_{x_0, z_0} = .001 \frac{(M1 - M0)}{(z1 - z0)} \quad \text{(M/km)}\ , \qquad (49)$$

where

$$M0 = M_{p,L} + K \ (M_{p+1,L} - M_{p,L}) \qquad \text{(M-units)}, \qquad (50)$$

and

$$M1 = M_{p,L+1} + K \ (M_{p+1,L+1} - M_{p,L+1}) \qquad \text{(M-units)}. \qquad (51)$$

Should it happen that the ground is reached and the layer boundaries are still equal, the local M-unit gradient is set to zero. Note that this technique also allows for the successful calculation of a zero M-unit gradient for real layers since $z1 \neq z0$. Control is then returned to the calling routine.

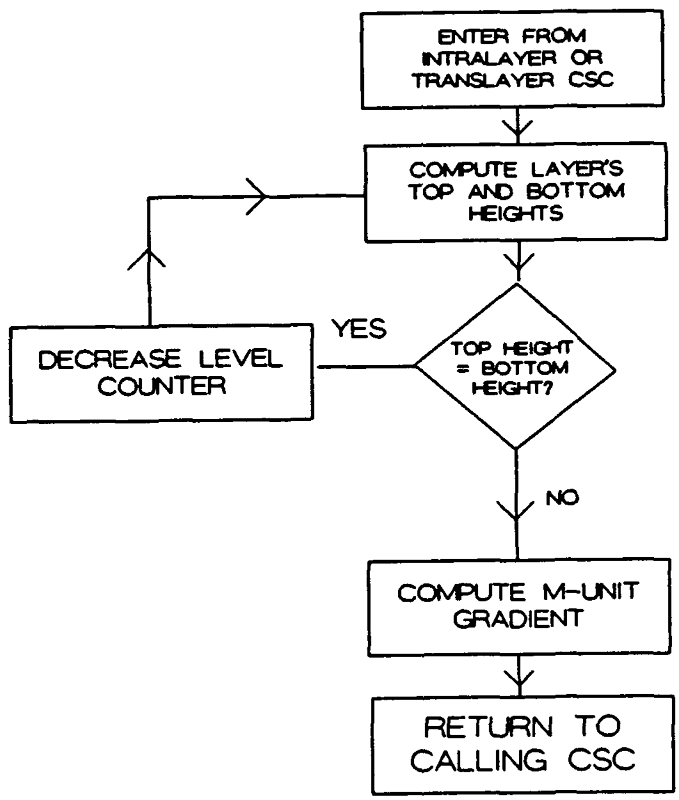

Figure 4.5-1. Program flow of the Mgrad CSC.

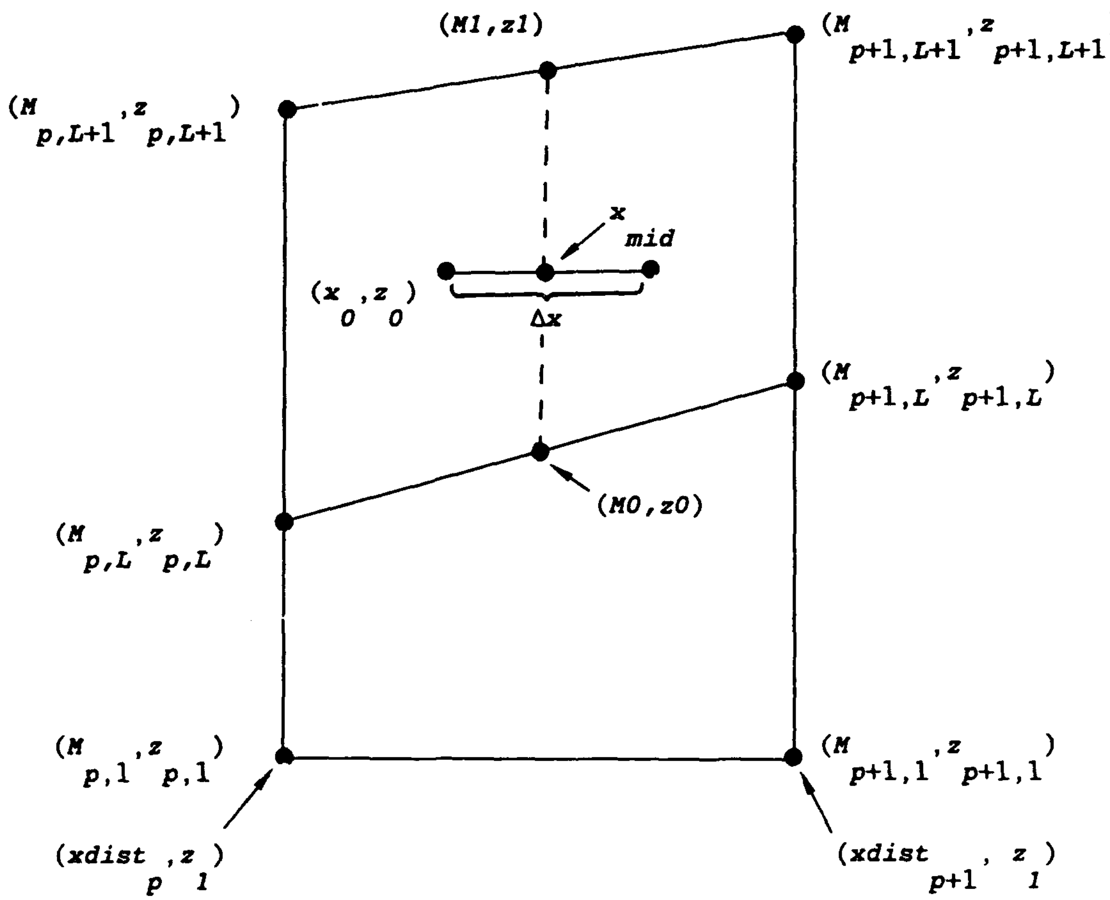

Figure 4.5-2. Definition of terms used by the Mgrad CSC.

5.0 CSCI DATA

The following tables describe the global data elements within the RTT CSCI. Table 5.0-1 specifies the data elements used by the RTT CSCI and lists the bounds of each data element, all of which are provided by the calling TESS CICI.

Tables 5.0-2 through 5.0-6 specify the data elements used by the Init CSC, Transprofile CSC, Intralayer CSC, Translayer CSC, and Mgrad CSC respectively. Within each table the CSC where the data element is calculated is listed.

Table 5.0-1. RTT CSCI data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit.

Name	Description	Data Type	Units	Bounds
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	1 to 5,000
z	and height	real	m	0 to 30,000
f_{res}	Range step resolution factor	real	N/A	> 0
pnumbr	Number of profiles	integer	N/A	≥ 1[a]
lnumbr	Number of profile levels	integer	N/A	≥ 2
$xdist_p$	Range from 1st to *p*th profile	real	km	0 to 1,000[b]
z_{tran}	Antenna height	real	m	1 to 30,000[c]
α_{start}	Ray initial launch angle	real	radians	-0.7853940 to 0.7853940

[a] If only one profile is available, it is input twice in order to define horizontally oriented layers. For the single profile case, the atmosphere would be homogeneous and the raytrace would not be range dependent.

[b] Maximum limit for practical purposes. In theory, unlimited.

[c] Maximum limit not to exceed the maximum height within a profile.

Specification of the radio-refractivity field, i.e., the profiles of M-units versus height, requires special consideration. The following requirements must be met.

The radio-refractivity field will consist of vertical piecewise linear profiles specified by couplets of height in meters above sea level and modified refractivity (M-units) at multiple arbitrary ranges. All vertical profiles must contain the same number of vertical data points and be specified such that each numbered data point corresponds to like-numbered points (i.e., features) in the other profiles. The first numbered data point of each profile must correspond to a height of zero and the last numbered data point must correspond to a height not less than the maximum height of the raytrace output. Within each profile, each numbered data point must correspond to a height level greater than or equal to the height at the previous data point. Note that a profile may contain redundant data points.

This specification allows a complicated refractivity field to be described with a minimum of data points. For example, a field in which a single trapping layer linearly descends with increasing range can be described with just two profiles containing only four data points each, frame (a) of figure 5.0-1. In the same manner, other evolutions of refractive layers may be described. Frames (b) and (c) of figure 5.0-1 show two possible scenarios for the development of a trapping layer. The scenario of choice is the one consistent with the true thermodynamical and hydrological layering of the atmosphere.

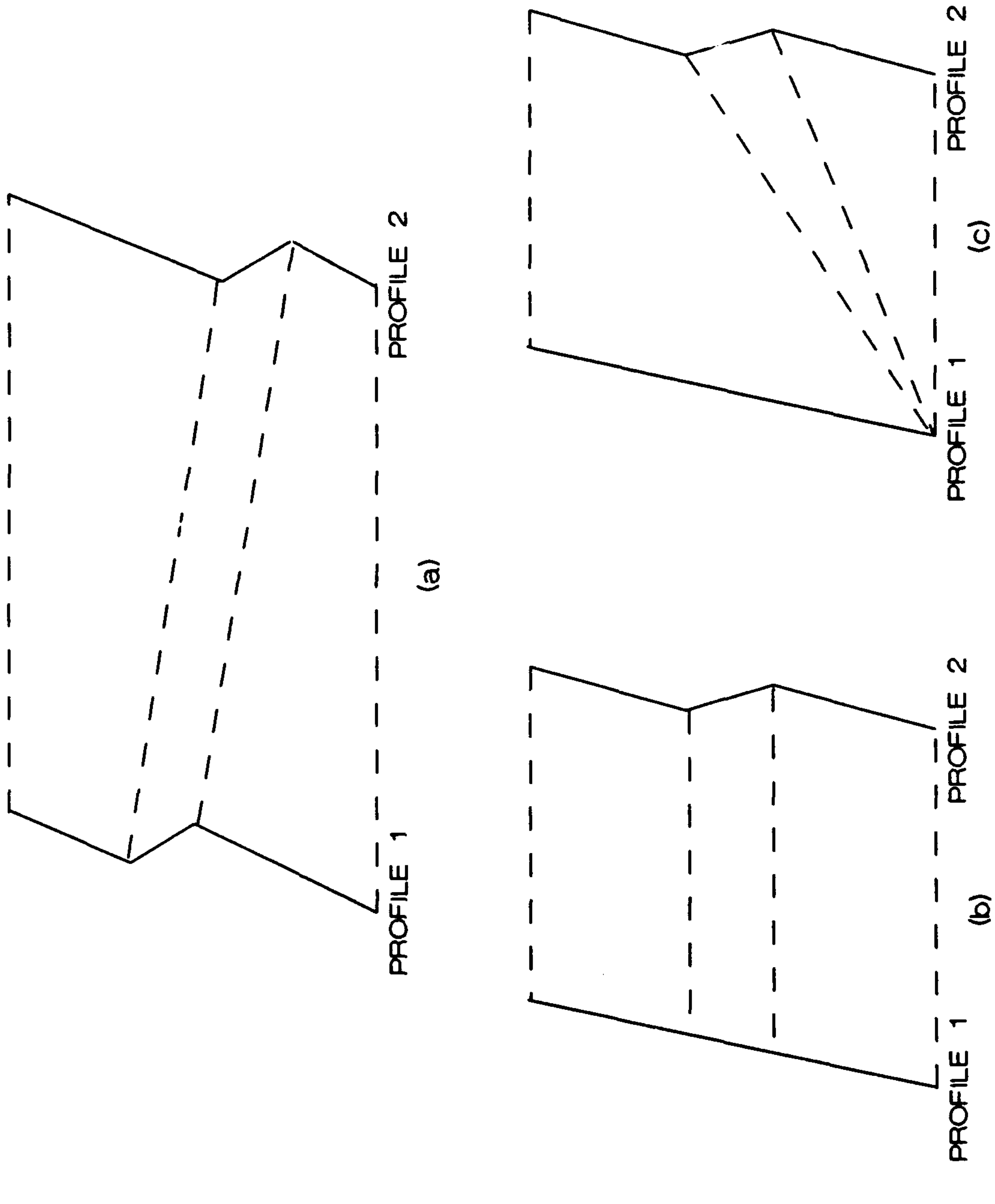

Figure 5.0-1. Idealized M-unit profiles (solid lines) and lines of interpolation (dashed lines).

Table 5.0-2. Init CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 5.0-1.

Name	Description	Data Type	Units	CSC Source
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	TESS CSCI
z	and height	real	m	TESS CSCI
pnumbr	Number of profiles	integer	N/A	TESS CSCI
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
z_{tran}	Antenna height	real	m	TESS CSCI

Table 5.0-3. Transprofile CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 5.0-1.

Name	Description	Data Type	Units	CSC Source
f_{res}	Range step resolution factor	real	N/A	TESS CSCI
pnumbr	Number of profiles	integer	N/A	TESS CSCI
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
z_{tran}	Antenna height	real	m	TESS CSCI
α_{start}	Angle	real	radians	TESS CSCI
L_{tran}	Level number corresponding to the bottom boundary of the layer containing the antenna height.	integer	N/A	Init
x_{max}	Maximum propagation range	real	km	Init
z_{max}	Maximum propagation height	real	m	Init
L	Level counter	integer	N/A	Intralayer
α_1	Ending angle	real	radians	Intralayer
x_1	Ending range	real	km	Intralayer
z_1	Ending height	real	m	Intralayer

Table 5.0-4. Intralayer CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 5.0-1.

Name	Description	Data Type	Units	CSC Source
lnumbr	Number of profile levels	integer	N/A	TESS CSCI
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
z_{max}	Maximum propagation height	real	m	Init
$\Delta z/\Delta x_{p,L}$	Layer boundary slope	real	m/km	Init
$\Delta M/\Delta z_{x_0,z_0}$	Local M-unit gradient	real	M/m	Mgrad
L	Level counter	integer	N/A	Transprofile
p	Profile counter	integer	N/A	Transprofile
x_0	Beginning range	real	km	Transprofile
z_0	Beginning height	real	m	Transprofile
α_0	Beginning angle	real	radians	Transprofile
x_{step}	Range step	real	km	Transprofile
x_{now}	Intermediate tracing range	real	km	Transprofile
L	Level counter	integer	N/A	Translayer
x_1	Ending range	real	km	Translayer
z_1	Ending height	real	m	Translayer
α_1	Ending angle	real	radians	Translayer

Table 5.0-5. Translayer CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 5.0-1.

Name	Description	Data Type	Units	CSC Source
$xdist_p$	Range from 1st to *p*th profile	real	km	TESS CSCI
$\Delta z/\Delta x_{p,L}$	Layer boundary slope	real	m/km	Init
α_0	Beginning angle	real	radians	Intralayer
α_1	Ending angle	real	radians	Intralayer
B_{x_0}	Layer bottom boundary height at beginning range	real	m	Intralayer
L	Level counter	integer	N/A	Intralayer
lyrflg	M-unit gradient flag	logical	N/A	Intralayer
p	Profile counter	integer	N/A	Intralayer
T_{x_0}	Layer top boundary height at beginning range	real	m	Intralayer
T_{x_1}	Layer top boundary height at ending range	real	m	Intralayer
x_1	Ending range	real	km	Intralayer
x_0	Beginning range	real	km	Intralayer
z_0	Beginning height	real	m	Intralayer
z_1	Ending height	real	m	Intralayer
$\Delta M/\Delta z_{x_0,z_0}$	Local M-unit gradient	real	M/m	Mgrad
x_{now}	Intermediate tracing range	real	km	Transprofile
x_{step}	Range step	real	km	Transprofile

Table 5.0-6. Mgrad CSC data element requirements. Real variables are assumed to have seven significant decimal digits and an exponent range of ± 64. Integer variables are assumed limited to ± 6535. Accuracy is ± 1 in the least significant digit. Bounds for TESS CSCI source variables are specified in table 5.0-1.

Name	Description	Data Type	Units	CSC Source
	Couplets of environmental profile data consisting of			
M	Modified refractivity	real	M	TESS CSCI
z	and height	real	m	TESS CSCI
$xdist_p$	Range from 1st to pth profile	real	km	TESS CSCI
L	Level counter	integer	N/A	Intralayer
p	Profile counter	integer	N/A	Intralayer
x_0	Beginning range	real	km	Intralayer
x_{mid}	Range to midpoint of ray segment	real	km	Translayer

6.0 CSCI DATA FILES

Not applicable

7.0 NOTES

The following is a listing of all abbreviations, variable names, and meanings used in this document.

a	Intermediate constant
A	Intermediate constant
b	Intermediate constant
c	Intermediate constant
C	Intermediate constant
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
α_0	Ray segment's beginning angle
α_1	Ray segment's ending angle
α_{start}	Initial ray angle
B_{x_0}	Layer bottom boundary height at beginning range
Δx	Intermediate range increment
$\Delta M/\Delta z_{x_0,z_0}$	M-unit gradient at the ray segment's beginning point
$\Delta z/\Delta x_{p,L}$	Layer boundary slope corresponding to the Lth level within the pth profile

f_{res}	Range step resolution factor
K	Ratio proportionality factor
L	Level counter
L_{tran}	Level number corresponding to the bottom boundary of the layer containing the antenna height.
lnumbr	Number of profile levels
lyrflg	M-unit gradient flag
M	Modified refractivity
M0	Modified refractivity at range x_0, height *z0*.
M1	Modified refractivity at range x_0, height *z1*.
OCD	Operational Concept Document
p	Profile counter
pnumbr	Number of profiles
RTT	Raytrace technique
SRS	Software Requirements Specification
TESS	Tactical Environmental Support System
T_{x_0}	Layer top boundary height at ray segment's beginning range
T_{x_1}	Layer top boundary height at ray segment's ending range
x_0	Ray segment's beginning range

x_1	Ray segment's ending range
$xdist_p$	Range from 1st to *p*th profile
x_{max}	Maximum propagation range
x_{mid}	Range to midpoint of ray segment
x_{now}	Intermediate tracing range, i.e., the range between the two adjacent profiles currently under consideration.
x_{step}	Range step
z_0	Ray segment's beginning height
z_1	Ray segment's ending height
z	Height
$z0$	Height of layer bottom boundary at the minimum of the ranges $x_0 + x_{step}/2$ or $x_0 + (xdist_{p+1} - x_0) / 2$
$z1$	Height of layer top boundary at the minimum of the ranges $x_0 + x_{step}/2$ or $x_0 + (xdist_{p+1} - x_0) / 2$
z_{max}	Maximum propagation height
z_{tran}	Antenna height

APPENDIX A - SAMPLE FORTRAN CODE

The following is a sample FORTRAN, with MIL-STD-1753, source code for the RTT CSCI.

```
c       PROGRAM:  RTRACE  (Raytrace)
c
c       PROCESS:
c
c          This program will trace a ray's path through an atmosphere
c          where the modified index of refraction is allowed to vary
c          both vertically and horizontally.
c
c          The subroutines contained within this program are:
c
c              init   (initialization) - initialize constants
c              tnspfl (transprofile) - loop for ray
c              intlyr (intralayer) - loop for each range step
c              tnslyr (translayer) - ray/boundary intercept calculation
c              mgrad  (M-unit gradient) - M-unit gradient calculation
c
c       SUBROUTINES CALLED:    SUBFUNCTIONS CALLED:   FORTRAN FUNCTIONS:
c
c            init                     none                    none
c            tnspfl
c
c       REQUIRED INPUTS:
c
c          through parameter list
c
c             none
c
c          through common block
c
c             the raytrace program requires inputs provided by the
c             calling TESS CSCI.  The inputs must be provided to the
c             raytrace program's common blocks prior to calling the INIT
c             (initialization) subroutine.  These inputs are:
c
c             1.  environmental profiles defined by couples of height
c                   (meters) and modified refractivity (M-units)
c             2.  number of environmental profiles
c             3.  number of profile levels
c             4.  horizontal range between first and each
c                   profile  (kilometers)
c             5.  antenna height (meters)
c             6.  starting propagation angle (radians)
c             7.  range step resolution factor
c
c          for this RTT, the maximum number of profiles is limited
c          to five and the maximum number of profile levels is limited
c          to 150.  This is for practicality only.  In theory, they are
c          only limited by the amount of computer memory.
```

```
c       OUTPUT PARAMETERS:
c
c          through common block
c
c             the raytrace program output consists of couplets of
c             range (kilometers) and height (meters) relative to a
c             starting point of zero range and zero height.  The
c             output points of range and height are available from
c             the subroutines TNSPFL (transprofile) or INTLYR
c             (interlayer) depending upon application using this
c             raytrace.
c
c          through parameter list
c             none
c
c       GLOSSARY:
c
c          The following is a complete glossary of every variable used
c          by all subroutines within the raytrace program
c
c          conventions:
c             variables beginning with "a" are associated with angles
c             variables beginning with "d" are associated with gradients
c             variables beginning with "l" are associated with layers
c             variables beginning with "p" are associated with profiles
c             variables beginning with "r" are associated with rays
c             variables beginning with "x" are associated with ranges
c             variables beginning with "z" are associated with heights
c
c          a      - intermediate constant
c                      (real  units = various)
c          anglea - angle opposite sidea of an oblique triangle
c                      (real  units = radians)
c          anglec - angle opposite sidec of an oblique triangle
c                      (real  units = radians)
c          aone   - ray segment ending angle
c                      (real  units = radians)
c          astep  - angle step size
c                      (real  units = radians)
c          astart - ray launch angle at range of zero
c                      (real  units = radians)
c          azero  - ray segment starting angle
c                      (real  units = radians)
c          b      - intermediate constant
c                      (real  units = various)
c          c      - intermediate constant
c                      (real  units = various)
c          d      - intermediate constant
c                      (real  units = various)
c          delx   - range between xzero and xone
c                      (real  units = kilometers)
c          delz   - length of a side of an oblique triangle
c                      (real  units = meters)
c          dmdz   - M-unit gradient at any local point (xzero,zzero)
c                      (real  units = M-units/meter)
c          dzdx   - slope of environmental layer
c                      (real array  units = meter/kilometer)
c          fres   - range step resolution factor
c                      (real)
```

```
c       k      - ratio proportionality factor
c                  (real)
c       l      - level counter
c                  (integer)
c       lnumbr - number of levels within a profile
c                  (integer)
c       ltran  - level immediately below transmitter height
c                  (integer)
c       lyrbtm - height of layer's bottom boundary at range xone
c                  (real  units = meters)
c       lyrflg - flag to indicate a layer of zero M-unit gradient
c                  (logical)
c       lyrsbm - height of layer's bottom boundary at range
c                 xzero  (real  units = meters)
c       lyrslp - slope of environemntal layer
c                  (real  units = radians)
c       lyrstp - height of layer's top boundary at range xzero
c                  (real  units = meters)
c       lyrtop - height of layer's top boundary at range xone
c                  (real  units = meters)
c       lyrxed - flag for boundary (top or bottom) being penetrated
c                  (character)
c       m      - M-unit profile
c                  (real array  units = M-units)
c       m0     - temporary variable
c                  (real  units = M-units)
c       m1     - temporary variable
c                  (real  units = M-units)
c       ok     - miscellaneous condition checking flag
c                  (character)
c       p      - profile counter
c                  (integer)
c       pnumbr - number of profiles
c                  (integer)
c       sidea  - length of a side of an oblique triangle
c                  (real  units = meters)
c       sideb  - lenght of a side of an oblique triangle
c                  (real  units = meters)
c       sidec  - lenght of a side of an oblique triangle
c                  (real  units = meters)
c       xdist  - range from 0 to the pth profile
c                  (real array  units = kilometers)
c       xmax   - maximum range
c                  (real  units = kilometers)
c       xmid   - ray segment midpoint range
c                  (real  units = kilometers)
c       xnow   - range from pth to pth+1 profile
c                  (real  units = kilometers)
c       xone   - ray segment ending range
c                  (real  units = kilometers)
c       xstep  - range step
c                  (real  units = kilometers)
c       xzero  - ray segment starting range
c                  (real  units = kilometers)
c       z      - height profile
c                  (real array  units = meters)
c       zmax   - maximum height of profile
c                  (real  units = meters)
```

```
c        zone    - ray segment ending height
c                     (real  units - meters)
c        zstep   - height step
c                     (real  units - meters)
c        ztran   - antenna height
c                     (real  units - meters)
c        zzero   - ray segment starting height
c                     (real  units - meters)
c        z0      - temporary variable
c                     (real  units - meters)
c        z1      - temporary variable
c                     (real  units - meters)
c
      program rtrace
c
c        Input EM system and environmental information from the TESS
c        database
c
c     call input routine
c
c        Initialize constants
c
      call init
c
c        Do raytrace calculations for a desired starting angle
c
      call tnspfl
      stop
      end
```

```
c       SUBROUTINE:  Init
c
c       PROCESS:
c
c           1.  Compute the maximum range and height
c           2.  Compute the layer boundary slopes
c           3.  Find the layer containing the transmitter height
c
c       SUBROUTINES CALLED:   SUBFUNCTIONS CALLED:   FORTRAN FUNCTIONS:
c
c            NONE                   NONE                   NONE
c
c       REQUIRED INPUTS:
c
c           through common block (variables provided by TESS CSCI)
c              lnumbr, m, pnumbr, xdist, z, ztran
c
c           through parameter list
c              NONE
c
c       OUTPUT PARAMETERS:
c
c           through common block
c              dzdx, ltran, xmax, zmax
c
c           through parameter list
c              NONE
c
      subroutine init
c
      integer      l, lnumbr, ltran, p, pnumbr
      real         astart
      real         dzdx(5,150), fres, m(5,150)
      real         xdist(5), xmax
      real         z(5,150), ztran, zmax
      character*3  ok
c
      common  /environment/  dzdx, fres, lnumbr, ltran,
     *                       m, pnumbr, xdist, xmax, z, zmax
c
      common  /emsystem/     astart, ztran
c
c        Set the maximum range and height based upon the
c        environmental input parameters
c
         xmax = xdist(pnumbr)
         zmax = z(1,lnumbr)
c
c        Compute the layer boundary and M-unit gradient slopes
c
      do p = 1, pnumbr -1
         do l = 1, lnumbr
            dzdx(p,l) = (z(p+1,l) - z(p,l)) / (xdist(p+1) - xdist(p))
         enddo
      enddo
```

```
c         Find the layer containing the transmitter height
c
      ok = " no"
      l = 1
      do while ((ok.eq." no") .and. (l.le.lnumbr))
         if (ztran .lt. z(l,l)) then
            l = l - 1
            ok = "yes"
         else if (ztran .eq. z(l,l)) then
            ok = "yes"
         else
            l = l + 1
         endif
      enddo
      ltran = l
      return
```

```
c      SUBROUTINE:   tnspfl  (Transprofile)
c
c      PROCESS:
c
c         1.  Initialize ray's starting range, height, and angle.
c         2.  Call for ending range, height, and angle.
c         3.  Increment profile counter when ray reached trace limits.
c         4.  Stop calculations when TESS limits reached
c
c      SUBROUTINES CALLING THIS SUBROUTINE:
c
c         init
c
c      SUBROUTINES CALLED:    SUBFUNCTIONS CALLED:   FORTRAN FUNCTIONS:
c
c         intlyr                      none                      float
c
c      REQUIRED INPUTS:
c
c         through parameter list
c            l
c
c         through common block
c            aone, astart, astep, fres, lnumbr, ltran, xdist, xmax
c            xone, zmax, zone, ztran
c
c      OUTPUT PARAMETERS:
c
c         through parameter list
c
c            l, p
c
c         through common block
c            azero, xnow, xstep, xzero, zzero
c
c
       subroutine tnspfl
c
       integer       l, lnumbr, pnumbr, p, ltran
       logical*2     lyrflg
       real          aone, astart, azero
       real          dmdz, dzdx(5,150)
       real          fres, lyrbtm, lyrsbm, lyrstp, lyrtop
       real          m(5,150)
       real          xdist(5), xmax, xnow, xone, xstep, xzero
       real          z(5,150), zmax, zone, ztran, zzero
       character*60 dummy
c
       common  /emsystem/     astart, ztran
c
       common  /environment/  dzdx, fres, lnumbr, ltran,
      *                       m, pnumbr, xdist, xmax, z, zmax
c
       common  /intermediate/ aone, azero, xone, xzero, zone, zzero
c
       common  /layer/        dmdz, lyrbtm, lyrflg, lyrsbm, lyrstp
      *                       lyrtop

       common  /trace/        xnow, xstep
```

```
c     Initialize profile and level counters, the beginning range,
c     height, and angle, and range step.
c
      azero - astart
      l - ltran
      p - 1
      xnow - xdist(p+1)
      xone - 0.
      xstep - xnow / fres
      xzero - 0.
      zone - ztran
      zzero - ztran
c
c     Start loop for range steps for ray.  range stepping
c     is continued until the maximum height or range is
c     reached.
c
      do while ((zzero .lt. zmax) .and. (xzero .lt. xmax) .and.
     *             (l .lt. lnumbr))
c
         call intlyr (p,l)
c
         if (aone .lt. 0.) .and. (zone.eq.0.) then
c           Special test fro rays with a zero height and a zero
c           angle.  Rather than considering this ray further, set
c           the range to the maximum so the raytrace will stop for
c           for this particular ray.
c
            xone - xmax
c
         else
c
c           ********************************************************
c
c           Note!
c
c           At this point, an application program may use the computed
c           range and height, depending upon the application.  For
c           example, if the application program was to plot the ray
            path on a display device, the call to a plotting routine
            would be inserted here.
c
c           ********************************************************
c
         endif
c
c        Reset the starting angle, range, and height in
c        preparation for the next range step
c
         azero - aone
         xzero - xone
         zzero - zone
c
```

```
c        If the ray has reached the next profile range but not
c        the maximum range, increment the profile counter and
c        recalculate the range step.
c
         if (xzero.eq.xnow .and. xzero.lt.xmax) then
            p = p + 1
            xnow = xdist(p+1)
           xstep = (xnow - xdist(p)) / fres
         endif
      enddo
c
      return
      stop
      end
```

```
c      SUBROUTINE:  intlyr (Intralayer)
c
c      PROCESS:
c
c         Given a ray segment's beginning angle, range, height,
c         and the environmental layer containing the segment, this
c         subroutine will:
c
c         1.  Determine if current layer is real with a nonzero M-unit
c               gradient, real with a zero M-unit gradient, or
c               artificial by virtue of two consecutive vertical data
c               points within a profile being the same.
c         2.  Compute ray segment's ending angle, range, and
c               height
c         3.  Determine if ray segment has penetrated the layer's
c               boundaries (either bottom, top, or end).
c         4.  If boundary has been crossed, call subroutine to compute
c               boundary/ray segment intercept angle, range, and
c               height.
c         5.  Reverse ray segment angle upon surface reflection.
c
c      SUBROUTINES CALLING THIS SUBROUTINE:
c
c         tnspfl
c
c      SUBROUTINES CALLED:    SUBFUNCTIONS CALLED:   FORTRAN FUNCTIONS:
c
c       tnslyr, mgrad                none                     tan
c
c      REQUIRED INPUTS:
c
c         through parameter list
c
c             l, p
c
c         through common block
c
c             aone, azero, dmdz, dzdx, lnumbr
c             xnow, xstep, xzero, z, zmax, zzero
c
c      OUTPUT PARAMETERS:
c
c         through parameter list
c
c             l
c
c         through common block
c
c             aone, lyrflg, lyrstp, lyrsbm, lyrtop
c             xone, zone
c
```

```
      subroutine intlyr (p,l)
c
      integer   l, lnumbr, ltran, p, pnumbr
      logical*2 lyrflg
      real      aone, azero
      real      delz, dmdz, dzdx(5,150)
      real      fres, lyrbtm, lyrnxt, lyrsbm, lyrstp, lyrtop
      real      m(5,150)
      real      xdist(5), xmax, xnow, xone, xstep, xzero
      real      z(5,150), zmax, zone, zzero
c
      common  /environment/ dzdx, fres, lnumbr, ltran,
     *                       m, pnumbr, xdist, xmax, z, zmax
c
      common  /intermediate/ aone, azero, xone, xzero, zone, zzero
c
      common  /layer/        dmdz, lyrbtm, lyrflg, lyrsbm, lyrstp
     *                       lyrtop
c
      common  /trace/        xnow, xstep

c        compute local M-gradient, layer's top and bottom height
c        ray's beginning range using point-slope equation
c
      call mgrad(p,l)
      lyrsbm = dzdx(p,l)   * (xzero - xdist(p)) + z(p,l)
      lyrstp = dzdx(p,l+1) * (xzero - xdist(p)) + z(p,l+1)
c
      if (dmdz.eq.0.) then
c
c        The layer is an actual layer, with thickness not equal to
c        zero, and with 0 M-unit gradient at each end.  In this case
c        the ray will travel in a straight line with ending angle the
c        same as the beginning angle.  Solve for ending values using
c        simple trig.  Do this in the code below.
c
         lyrflg = .false.
      else
         lyrflg = .true.
      endif
c
      if (l.eq.0) then
c
c        the real boundary is at the surface so allow for reflection,
c        i.e., set height to zero and reverse angle of ray.
c
      elseif (l.gt.lnumbr) then
c
c        The first real boundary is at the top of the profile so set
c        the height to the maximum and stop drawing this ray.
c
         zone = zmax
      else
c
c        Compute the ending range
c
         xone = xzero + xstep
```

```
c        If the computed ending range is beyond the next profile
c        range, reset the ending range to the profile range.
c
         if (xone .gt. xnow) xone = xnow
c
c        Compute ending angle
c
         if (lyrflg) then
c           true nonzero M-unit layer so use standard raytrace
c           equation to solve for ending angle
c
            aone = azero + dmdz * (xone - xzero)
c
c           Check to see if ray has turned around within the layer and
c           if so, set the ending angle to zero and recompute the
c           height to this maximum or minimum point
c
            if ((azero.lt.0. .and. aone.ge.0.) .or.
     *          (azero.gt.0. .and. aone.le.0.)) then
               aone = 0.
               xone = xzero - azero/dmdz
            endif
         else
c           true zero M-unit layer so ray segment is straight.  set
c           ending angle equal to starting angle
c
            aone = azero
         endif
c
c        Compute ending height
c
         if (lyrflg) then
c           true nonzero M-unit layer so use standard raytrace
c           equation to solve for ending height
c
            zone = zzero + (aone**2 - azero**2) / (2.e-3 * dmdz)
         else
c           true zero M-unit layer so ray segment is straight.  Use
c           simple trig to solve for ending height
c
            delz = tan(azero) * ((xone - xzero) * 1000.0)
            zone = zzero + delz
         endif
c
c        Compute layer's top and bottom height at ray's ending
c        range
c
         lyrtop = dzdx(p,l+1) * (xone - xdist(p)) + z(p,l+1)
         lyrbtm = dzdx(p,l) * (xone - xdist(p)) + z(p,l)
c
c        If the ending altitude is outside of the layer, compute the
c        ray/layer intercept point
c
         if (zzero.eq.lyrsbm .and. zone.lt.lyrbtm) then
c           special case for ray starting at bottom boundary and
c           penetrating into layer below.  If the ray has not
c           completely penetrated the layer below, accept the
```

```
c           calculated range, height, and angle.  If the ray has
c           also penetrated this layer, compute the penetration
c           point.
c
            l = l - 1
            lyrnxt = dzdx(p,l) * (xone - xdist(p)) + z(p,l)
            if (zone.lt.lyrnxt) call tnslyr (p,l)
c
         elseif (zone.gt.lyrtop .or. zone.lt.lyrbtm) then
c           ray has penetrated layer boundary so compute values
c           at boundary crossing point
c
            call tnslyr (p,l)
         endif
      endif
c
c        Check to see if the ray has reached the ground.  If so,
c        reverse the angle to simulate surface reflection
c
      if (l .le. 0.) then
         l = 1
         aone = -aone
         zone = 0.
      endif
c
      return
      stop
      end
```

```
c       SUBROUTINE:  tnslyr  (Translayer)
c
c       PROCESS:
c
c          Given a ray segment's starting angle, range, height, and
c          an environmental layer's boundary being penetrated by the
c          ray segment, this subroutine will:
c
c             1.  Compute the boundary/ray segment penetration angle,
c                 range, and height.
c
c       SUBROUTINES CALLING THIS SUBROUTINE:
c
c          intlyr
c
c       SUBROUTINES CALLED:    SUBFUNCTIONS CALLED:    FORTRAN FUNCTIONS:
c
c          mgrad                       none                   abs
c                                                             cos
c                                                             sin
c                                                             tan
                                                              sqrt
c
c       REQUIRED INPUTS:
c
c          through parameter list
c
c             l, p
c
c          through common block
c
c             azero, dzdx, lyrflg, lyrsbm, lyrstp, lyrtop
c             xnow, xstep, xzero, z, zone, zzero
c
c       OUTPUT PARAMETERS:
c
c          through parameter list
c
c             l, p, xmid
c
c          through common block
c
c             aone, xone, zone
c
c
        subroutine tnslyr (p,l)
c
        character*3   lyrxed
        integer       l, lnumbr, ltran, p, pnumbr
        logical*2     lyrflg
        real          a, anglea, angleb, anglec, aone, azero
        real          b, c, d
        real          delx, delz, dmdz, dzdx(5,150)
        real          fres, lyrbtm, lyrsbm, lyrslp, lyrstp, lyrtop
        real          m(5,150)
        real          sidea, sideb
        real          xdist(5), xmax, xmid, xnow, xone, xstep, xzero
        real          z(5,150), zmax, zone, zzero
```

```
      common  /environment/  dzdx, fres, lnumbr, ltran,
     *                  .    m, pnumbr, xdist, xmax, z, zmax
c
      common  /intermediate/ aone, azero, xone, xzero, zone, zzero
c
      common  /layer/        dmdz, lyrbtm, lyrflg, lyrsbm, lyrstp
     *                       lyrtop
c
      common  /trace/        xnow, xstep
c
c        Determine which layer boundary was crossed, the top or
c        the bottom

      if (zone .gt. lyrtop) then
c        ray has crossed layer's top boundary so increment layer
c        counter to use top boundary for this and future range
c        step calculations
c
         l = l + 1
         lyrxed = "top"
      else
         lyrxed = "btm"
      endif
c
      if (lyrflg) then
c
c        Ray within a layer with M-unit gradient not equal to zero.
c        Therefore, ray-path is curved line. Calculate the
c        coefficients for the quadradic equation used to solve for
c        range and height at which the ray segment crosses the
c        layer boundry
c
         a = dmdz / 2.e-3
         b = 2. * azero / 2.e-3 - dzdx(p,l)
         c = zzero - dzdx(p,l) * (xzero - xdist(p)) - z(p,l)
         d = sqrt(b**2 - 4. *a *c)
c
c        Solve the quadratic equation using the basic quadratic
c        formula
c
         delx = (-b + d) / (2. * a)
         if ((delx .lt. 0.) .or. (delx .gt. xstep))
     *        delx = abs((-b - d) / (2. * a))
c
c        Calculate the ray segment's ending range, checking to see
c        if it has exceeded the range to the next profile.
c
         xone = xzero + delx
         if (xone .gt. xnow) xone = xnow
c
c        Calculate the ray segment's ending height and angle at the
c        point where the ray crossed the boundary
c
         xmid = xzero + (xone - xzero) / 2.
         call mgrad (p,l,xmid)
         aone = azero + dmdz * (xone - xzero)
```

```
c       Check to see if ray, in reality, passed through a local
c       maximum or minimum before it crossed the boundary.  If so,
c       use simple trig to calculate the range and angle at the
c       actual boundary crossing.
c
        if (lyrxed .eq. "btm") sidea = zzero - lyrsbm
        if (lyrxed .eq. "top") sidea = lyrstp - zzero
c
        if (azero.lt.0. .and. aone.gt.0.) .or.
     *     (azero.gt.0. .and. aone.lt.0.) then
           anglea = abs(azero)
           angleb = 1.5707963 - abs(azero)
           anglec = 1.5707963 - abs(lyrslp)
           sideb = sidea * sin(angleb) / sin(anglea)
           delr = sideb * sin(anglec) / 1000.
           xone = xzero + delr
           xmid = xzero + (xone - xzero) / 2.
           call mgrad (p,l,xmid)
           aone = azero + dmdz * (xone - xzero)
        endif
c
        zone = dzdx(p,l) * (xone - xdist(p)) + z(p,l)
c
     else
c
c       Ray within a layer with M-unit gradient equal to zero.
c       Therefore, ray-path is straight line.  Use simple trig
c       (two angles with an included side of an oblique triangle)
c       to solve for range at which the ray segment crosses the
c       layer's boundry
c
c       convert layer's slope from m/km to radians
        lyrslp = abs(dzdx(p,l)) / 1000.0
c
        if (azero.ne.0. .and. abs(azero) .gt. lyrslp) .or.
    *      (lyrslp .eq. 0.) then
           anglea = abs(azero) - lyrslp
           anglec = 1.5707963 + lyrslp
        elseif (abs(azero) .lt. lyrslp) .or. (azero .eq. 0.) then
           anglea = lyrslp - abs(azero)
           anglec = 1.5707963 + abs(azero)
        endif
c
        sidec = sidea * sin(anglec) / sin(anglea)
c
c       convert range from meters to kilometers and use simple
c       trig to solve for ending height
c
        delx = (sidec * cos(abs(azero))) / 1000.0
        xone = xzero + delx
c
        if (xone .gt. xnow) then
           xone = xnow
           delx = (xone - xzero) * 1000.
           zone = zzero + delx * tan(azero)
        else
           zone = zzero + sidec * sin(azero)
        endif
```

```
c         set ending angle equal to starting angle since ray segment
c         is straight
c
          aone = azero
      endif
c
      if (lyrxed .eq. "btm") then
c         ray has crossed layer's bottom boundary so reset layer
c         counter for next range step calculations
          l = l - 1
      endif
      return
      stop
      end
```

```
c       SUBROUTINE:  Mgrad
c
c       PROCESS:
c
c           1.  Compute the vertical M-unit gradient for each layer
c
c       SUBROUTINES CALLED:   SUBFUNCTIONS CALLED:   FORTRAN FUNCTIONS:
c
c            NONE                   NONE                   aminl
c
c       REQUIRED INPUTS:
c
c           through common block
c
c              m, xdist, xzero, z
c
c           through parameter list
c
c              l, p, xmid
c
c       OUTPUT PARAMETERS:
c
c           through common block
c              dmdz
c
c           through parameter list
c              NONE
c
      subroutine mgrad(p, l, xmid)
c
c
      integer       j, lnumbr, ltran, p, pnumbr
      logical*2     lyrflg
      real          aone, azero
      real          delx, dmdz, dzdx(5,150)
      real          fres, k, lyrbtm, lyrsbm, lyrslp, lyrstp, lyrtop
      real          m(5,150), m0, ml
      real          xdist(5), xmax, xmid, xnow, xone, xstep, xzero
      real          z(5,150), zmax, zone, zzero, z0, zl
c
c
      common  /environment/  dzdx, fres, lnumbr, ltran,
     *                       m, pnumbr, xdist, xmax, z, zmax
c
      common  /intermediate/ aone, azero, xone, xzero, zone, zzero
c
      common  /layer/        dmdz, lyrbtm, lyrflg, lyrsbm, lyrstp,
     *                       lyrtop
c
c         Set temporary variables and compute the range ratio
c         proportionality constant
c
      j = 1
      k = (xmid - xdist(p)) / (xdist(p+l) - xdist(p))
```

```
c        Compute the layer's top and bottom heights at the range
c        of xzero.
c
      z0 = z(p,j) + k * (z(p+1,j) - z(p,j))
      z1 = z(p,j+1) + k * (z(p+1,j+1) - z(p,j+1)

c        This layer may be an artificial layer created by having two
c        consecutive vertical data points within a profile being the
c        same.  This condition is created because each profile
c        must contain the same number of data points.  Therefore, a
c        boundary may exist with the layer above and below the
c        boundary actually being the same layer.
c
      if (z0 .eq. z1) then
c
c           The layer is artificial. Increment the layer counter
c           downward until a real boundary is found or until the
c           ground is reached.
c
            do while (z0 .eq. z1) .and. (j .gt. 0.)
               j = j - 1
               z0 = z(p,j) + k * (z(p+1,j) - z(p,j))
               z1 = z(p,j+1) + k * (z(p+1,j+1) - z(p,j+1)
            end do
         endif
      endif
c
      m0 = m(p,j) + k * (m(p+1,j) - m(p,j))
      m1 = m(p,j+1) + k * (m(p+1,j+1) - m(p,j+1)
      if (z1 .eq. z0) then
         dmdz = 0.
      else
         dmdz = .001 * (m1 - m0) / (z1 - z0)
      endif
c
      return
      stop
      end
```

SOFTWARE TEST DESCRIPTION

FOR THE

RAYTRACE TECHNIQUE FOR A LATERALLY

HETEROGENEOUS ENVIRONMENT

30 September 1990

Prepared for:

Space and Naval Warfare Systems Command (PMW-141)

Prepared by:

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San Diego, CA 92152-5000

CONTENTS

FIGURES

TABLES

1.0 SCOPE

1.1 Identification

A raytrace technique for a laterally heterogeneous environment.

1.2 Document Overview

This document specifies the test cases necessary to perform formal qualification testing of the raytrace technique.

2.0 REFERENCE DOCUMENTS

(a) Commander-In-Chief, Pacific Fleet Meteorological Requirement (PAC MET) 87-04, "Range Dependent Electromagnetic Propagation Models."

(b) Naval Oceanographic Office, "Software Documentation Standards and Coding Requirements for Environmental System Product Development," Sep. 1988

(c) Naval Ocean Systems Center (NOSC) Technical Report 1180, "A Raytrace Method for a Laterally Heterogeneous Environment," Jul. 1987.

(d) NOSC "Operational Concept Document for the Raytrace Technique for a Laterally Heterogeneous Environment," Sep. 1990.

(e) NOSC "Software Requirements Specification for the Raytrace Technique for a Laterally Heterogeneous Environment," Sep. 1990.

(f) NOSC "Software Design Document for the Raytrace Technique for a Laterally Heterogeneous Environment," Sep. 1990.

3.0 FORMAL QUALIFICATION TEST DESCRIPTIONS

3.1 Test Case 1

The purpose of this test case is to

a. Exercise the Init CSC by
   (1) computing a level slope for each horizontally oriented layer as defined by adjacent profiles, and
   (2) determining the level number corresponding to the bottom boundary of the layer containing the antenna height.

b. Exercise the Transprofile CSC by
   (1) setting the profile and level counters,
   (2) determining the range step and intermediate tracing range,
   (3) initializing the beginning range, height, and angle, and
   (4) comparing the ending height with the calling TESS CSCI termination conditions

c. Exercise the Intralayer CSC by
   (1) determining for a nonzero M-unit gradient layer and a beginning height equal to a level height; an ending range, height, and angle, both within the layer and upon surface reflection of the ray, and
   (2) determining if the ray has penetrated the layer bounds in either range or height.

d. Exercise the Translayer CSC by
   (1) determine a maximum propagation range and height based upon environmental inputs and,
   (2) computing a range, height, and angle at a ray/layer boundary intercept under conditions of a nonzero M-unit gradient layer, a positive and negative penetration angle, and a zero and positive sloping boundary.

e. Exercise the Mgrad CSC by
   (1) computing an M-unit gradient at a local range and height.

3.1.1 Test Inputs

Variable names, description, units, and input values for test case 1 are listed in table 3.1.1-1.

Table 3.1.1-1. Test case 1 data element inputs.

	Profile 1		Profile 2	
Level	Height (m)	M-unit (M)	Height (m)	M-unit (M)
1	.0	340.0	.0	340.0
2	1000.0	458.0	2000.0	576.0
3	2000.0	400.0	3000.0	518.0
4	3000.0	518.0	4000.0	636.0
5	4000.0	636.0	4500.0	695.0
6	5000.0	754.0	5000.0	754.0

f_{res}	Range step resolution factor	=	50
pnumbr	Number of profiles	=	2
lnumbr	Number of profile levels	=	6
$xdist_1$	Range to first profile	=	0 km
$xdist_2$	Range to second profile	=	200 km
z_{tran}	Antenna height	=	1000 m
α_{start}	Initial angle	=	-.0392699 radians

3.1.2 Expected Test Results

Variable names, description, units and expected test results for test case 1 are listed in table 3.1.2-1.

Table 3.1.2-1. Expected test results from test case 1.

a. Exercise of Init CSC to establish constants.

level slopes

$\Delta z/\Delta x_{p,L}$

L	p=1	p=2
1	.0000000	.0000000
2	5.0000000	.0000000
3	5.0000000	.0000000
4	5.0000000	.0000000
5	2.5000000	.0000000
6	.0000000	.0000000

antenna level

$L_{tran} = 2$

b. Exercise of Transprofile CSC to establish initial conditions.

profile counter (p)	= 1
level counter (L)	= 2
range step (x_{step})	= 4.0 km
intermediate tracing range (x_{now})	= 200.0 km
maximum propagation range (x_{max})	= 200 km
maximum propagation height (z_{max})	= 5000 m
beginning range (x_0)	= 0.0 km
beginning height (z_0)	= 1000.0 m
beginning angle (α_0)	= -.0392699 radians

Table 3.1.2-1. Expected test results from test case 1 (cont).

c. Exercise of Intralayer, Translayer, and Mgrad CSCs to determine intermediate ranges, heights, angles, M-unit gradients, and ray/layer boundary intercept points.

Layer	M-gradient $\Delta M/\Delta z_{x_0, z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Ray penetrated downward into layer 1 - values before calling and returned from Translayer CSC are							
2	-0.0000580	0.0	4.0	1000.0	842.5	-0.0392699	-0.0395019
1		0.0	4.0	1000.0	842.5	-0.0392699	-0.0395019
Values returned from Intralayer CSC are							
1	0.0001180	4.0	8.0	842.5	685.4	-0.0395019	-0.0390299
1	0.0001180	8.0	12.0	685.4	530.2	-0.0390299	-0.0385579
1	0.0001180	12.0	16.0	530.2	376.9	-0.0385579	-0.0380859
1	0.0001180	16.0	20.0	376.9	225.5	-0.0380859	-0.0376139
1	0.0001180	20.0	24.0	225.5	76.0	-0.0376139	-0.0371419
Ray reflected from surface - value before calling and returned from Translayer CSC are							
1	0.0001180	24.0	28.0	76.0	-71.6	-0.0371419	-0.0366699
1		24.0	26.1	76.0	0.0	-0.0371419	0.0368996

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1120.0	1140.0	0.0	0.0

Table 3.1.2-1. Expected test results from test case 1 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
1	0.0001180	26.1	30.1	0.0	148.5	0.0368996	0.0373716
1	0.0001180	30.1	34.1	148.5	299.0	0.0373716	0.0378436
1	0.0001180	34.1	38.1	299.0	451.3	0.0378436	0.0383156
1	0.0001180	38.1	42.1	451.3	605.5	0.0383156	0.0387876
1	0.0001180	42.1	46.1	605.5	761.6	0.0387876	0.0392596
1	0.0001180	46.1	50.1	761.6	919.6	0.0392596	0.0397316
1	0.0001180	50.1	54.1	919.6	1079.4	0.0397316	0.0402036
1	0.0001180	54.1	58.1	1079.4	1241.2	0.0402036	0.0406756
Ray penetrated upward into layer 2 - value before calling and returned from Translayer CSC are							
1	0.0001180	58.1	62.1	1241.2	1404.9	0.0406756	0.0411476
2		58.1	59.4	1241.2	1297.1	0.0406756	0.0405960

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1290.3	1310.3	0.0	0.0

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
2	-0.0000580	59.4	63.4	1297.1	1459.0	0.0405960	0.0403640
2	-0.0000580	63.4	67.4	1459.0	1620.0	0.0403640	0.0401320
2	-0.0000580	67.4	71.4	1620.0	1780.1	0.0401320	0.0399000
2	-0.0000580	71.4	75.4	1780.1	1939.2	0.0399000	0.0396680
2	-0.0000580	75.4	79.4	1939.2	2097.4	0.0396680	0.0394360
2	-0.0000580	79.4	83.4	2097.4	2254.7	0.0394360	0.0392040
2	-0.0000580	83.4	87.4	2254.7	2411.1	0.0392040	0.0389720

Table 3.1.2-1. Expected test results from test case 1 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0, z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Ray penetrated upward into layer 3 - value before calling and returned from Translayer CSC are							
2	-0.0000580	87.4	91.4	2411.1	2566.5	0.0389720	0.0387400
3		87.2	88.2	2411.1	2441.0	0.0389720	0.0390626

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
2437.1	2457.1	1437.1	1457.1

Layer	M-gradient $\Delta M/\Delta z_{x_0, z_0}$	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
3	0.0001180	88.2	92.2	2441.0	2598.2	0.0390626	0.0395346
3	0.0001180	92.2	96.2	2598.2	2757.2	0.0395346	0.0400066
3	0.0001180	96.2	100.2	2757.2	2918.2	0.0400066	0.0404786
3	0.0001180	100.2	104.2	2918.2	3081.1	0.0404786	0.0409506
3	0.0001180	104.2	108.2	3081.1	3245.8	0.0409506	0.0414226
3	0.0001180	108.2	112.2	3245.8	3412.5	0.0414226	0.0418946
Ray penetrated upward into layer 4 - value before calling and returned from Translayer CSC							
3	0.0001180	112.2	116.2	3412.5	3581.0	0.0418946	0.0423666
4		112.2	116.2	3412.5	3581.0	0.0418946	0.0423665

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
3561.0	3581.0	2561.0	2581.0

Table 3.1.2-1. Expected test results from test case 1 (cont).

Layer	M-gradient	Range (km)		Height (m)		Angle (radians)	
	$\Delta M/\Delta z_{x_0,z_0}$	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
4	0.0001180	116.2	120.2	3581.0	3751.4	0.0423665	0.0428385
4	0.0001180	120.2	124.2	3751.4	3923.7	0.0428385	0.0433105
4	0.0001180	124.2	128.2	3923.7	4097.9	0.0433105	0.0437825
4	0.0001180	128.2	132.2	4097.9	4273.9	0.0437825	0.0442545
Ray penetrated upward into layer 5 - value before calling and returned from Translayer CSC are							
4	0.0001180	132.2	136.2	4273.9	4451.9	0.0442545	0.0447265
5		132.2	133.5	4273.9	4333.9	0.0442545	0.0444141

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
4330.5	4340.5	3661.0	3681.0

Layer	M-gradient	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
5	0.0001180	133.5	137.5	4333.9	4512.5	0.0444141	0.0448861
5	0.0001180	137.5	141.5	4512.5	4692.9	0.0448861	0.0453581
5	0.0001180	141.5	145.5	4692.9	4875.3	0.0453581	0.0458301
Ray exceeded maximum height - value before calling and returned from Translayer CSC are							
5	0.0001180	145.5	149.5	4875.3	5059.6	0.0458301	0.0463021
6		145.5	148.3	4875.3	5000.0	0.0458301	0.0462389

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
5000.0	5000.0	4363.9	4373.9

Transprofile CSC determines height terminating conditions are met. Any or all values of range (x_1) and height (z_1) may be returned to the calling TESS CSCI depending upon the TESS CSCI application. While not a part of the RTT, figure 3.1.2-1 illustrates a graphic of all intermediate range/height values as a visualization aid in test evaluation.

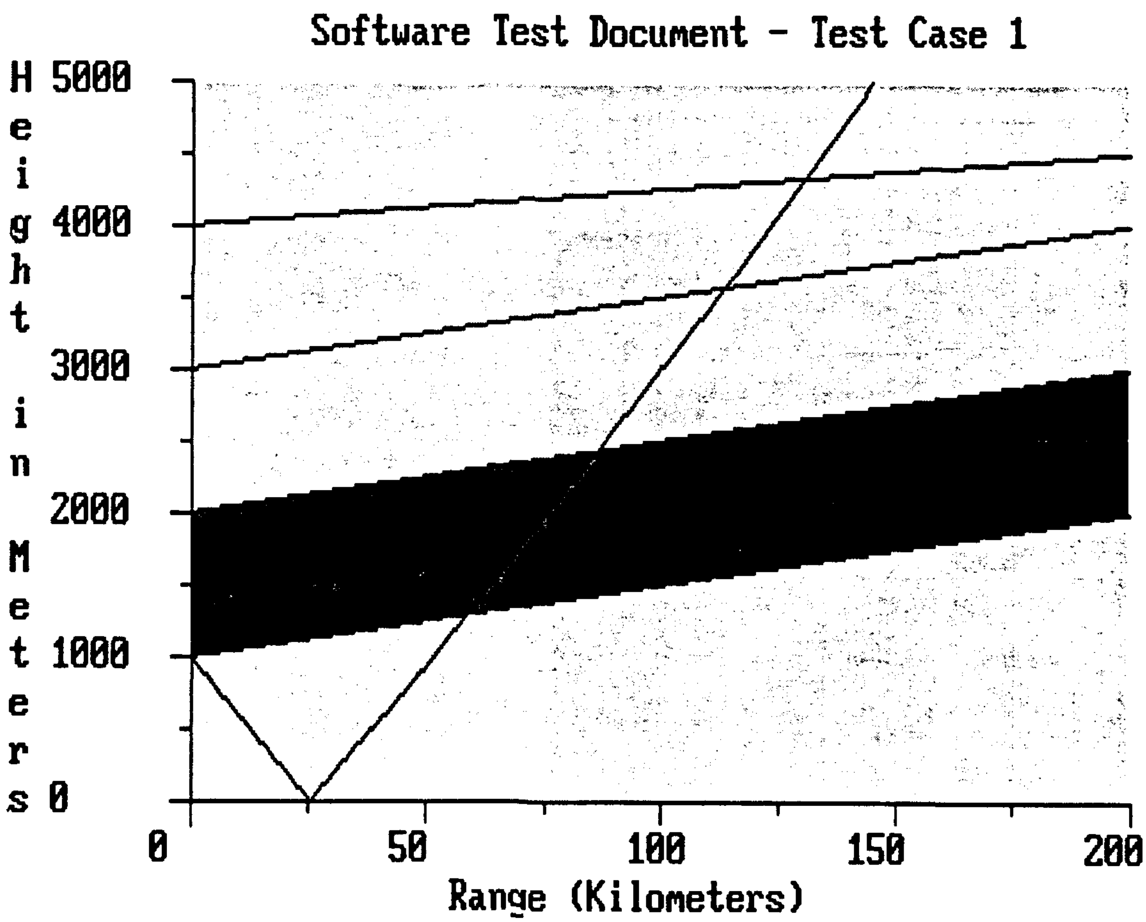

Figure 3.1.2-1. Test case 1 graphic display of intermediate results.

3.1.3 Criteria for Evaluating Results

The calculated range and height must be ± 1 of the least significant digit of the final values of table 3.1.2-1.

3.1.4 Test Procedure

1. An input data file is created by the tester as a text file.
2. The RTT CSCI is executed in a form that reads the input data file, performs the calculations, and writes the output to a text file.
3. The output file is compared to the final expected test results to determine satisfactory performance.

All test case procedures will be performed in this same manner.

3.1.5 Assumptions and Constraints

Input data elements are assumed to be constrained by the limits listed within table 3.4-1 of the Software Requirements Specification.

3.2 Test Case 2

The purpose of this test case is to

a. Exercise the Intralayer CSC by
   (1) determining for a non-zero M-unit gradient layer, an ending range, height, and angle for a ray which passes through a local maximum or minimum point.

b. Exercise the Transprofile CSC by
   (1) comparing the calculated range with the calling TESS CSCI termination conditions.

3.2.1 Test Inputs

Variable names, description, type, units and input values for test case 2 are listed in table 3.1.1-1 with the exception of the initial angle (α_{start}) which is -.0087266 radians for this test case.

3.2.2 Expected Test Results

Variable names, description, units and expected test results for the test case 2 are listed in table 3.1.2-1, sections (a) and (b) except for the beginning angle (α_0) which is -.0087266 radians; and in table 3.2.2-1.

Table 3.2.2-1. Expected test results from test case 2

Layer	M-gradient	Range (km)		Height (m)		Angle (radians)	
	$\Delta M/\Delta z_{x_0,z_0}$	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
1	-0.0000580	0.0	4.0	1000.0	964.6	-0.0087266	-0.0089586
1	0.0001180	4.0	8.0	964.6	929.7	-0.0089586	-0.0084866
1	0.0001180	8.0	12.0	929.7	896.7	-0.0084866	-0.0080146
1	0.0001180	12.0	16.0	896.7	865.6	-0.0080146	-0.0075426
1	0.0001180	16.0	20.0	865.6	836.4	-0.0075426	-0.0070706
1	0.0001180	20.0	24.0	836.4	809.1	-0.0070706	-0.0065986
1	0.0001180	24.0	28.0	809.1	783.6	-0.0065986	-0.0061266
1	0.0001180	28.0	32.0	783.6	760.0	-0.0061266	-0.0056546
1	0.0001180	32.0	36.0	760.0	738.4	-0.0056546	-0.0051826
1	0.0001180	36.0	40.0	738.4	718.6	-0.0051826	-0.0047106
1	0.0001180	40.0	44.0	718.6	700.7	-0.0047106	-0.0042386

Table 3.2.2-1. Expected test results from test case 2 (cont)

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
1	0.0001180	44.0	48.0	700.7	684.7	-0.0042386	-0.0037666
1	0.0001180	48.0	52.0	684.7	670.6	-0.0037666	-0.0032946
1	0.0001180	52.0	56.0	670.6	658.3	-0.0032946	-0.0028226
1	0.0001180	56.0	60.0	658.3	648.0	-0.0028226	-0.0023506
1	0.0001180	60.0	64.0	648.0	639.5	-0.0023506	-0.0018786
1	0.0001180	64.0	68.0	639.5	632.9	-0.0018786	-0.0014066
1	0.0001180	68.0	72.0	632.9	628.3	-0.0014066	-0.0009346
1	0.0001180	72.0	76.0	628.3	625.5	-0.0009346	-0.0004626
Ray passed through minimum (Intralayer CSC) - values before and after minimum angle recalculation are							
1	0.0001180	76.0	80.0	625.5	625.5	-0.0004626	0.0000094
1	0.0001180	76.0	79.9	625.5	624.6	-0.0004626	0.0000000
Values returned from Intralayer CSC are							
1	0.0001180	79.9	83.9	624.6	625.5	0.0000000	0.0004720
1	0.0001180	83.9	87.9	625.5	628.3	0.0004720	0.0009440
1	0.0001180	87.9	91.9	628.3	633.1	0.0009440	0.0014160
1	0.0001180	91.9	95.9	633.1	639.7	0.0014160	0.0018880
1	0.0001180	95.9	99.9	639.7	648.2	0.0018880	0.0023600
1	0.0001180	99.9	103.9	648.2	658.5	0.0023600	0.0028320
1	0.0001180	103.9	107.9	658.5	670.8	0.0028320	0.0033040
1	0.0001180	107.9	111.9	670.8	685.0	0.0033040	0.0037760
1	0.0001180	111.9	115.9	685.0	701.0	0.0037760	0.0042480
1	0.0001180	115.9	119.9	701.0	719.0	0.0042480	0.0047200
1	0.0001180	119.9	123.9	719.0	738.8	0.0047200	0.0051920
1	0.0001180	123.9	127.9	738.8	760.5	0.0051920	0.0056640
1	0.0001180	127.9	131.9	760.5	784.1	0.0056640	0.0061360

Table 3.2.2-1. Expected test results from test case 2 (cont)

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
1	0.0001180	131.9	135.9	784.1	809.6	0.0061360	0.0066080
1	0.0001180	135.9	139.9	809.6	837.0	0.0066080	0.0070800
1	0.0001180	139.9	143.9	837.0	866.2	0.0070800	0.0075520
1	0.0001180	143.9	147.9	866.2	897.4	0.0075520	0.0080240
1	0.0001180	147.9	151.9	897.4	930.4	0.0080240	0.0084960
1	0.0001180	151.9	155.9	930.4	965.3	0.0084960	0.0089680
1	0.0001180	155.9	159.9	965.3	1002.2	0.0089680	0.0094400
1	0.0001180	159.9	163.9	1002.2	1040.9	0.0094400	0.0099120
1	0.0001180	163.9	167.9	1040.9	1081.5	0.0099120	0.0103840
1	0.0001180	167.9	171.9	1081.5	1123.9	0.0103840	0.0108560
1	0.0001180	171.9	175.9	1123.9	1168.3	0.0108560	0.0113280
1	0.0001180	175.9	179.9	1168.3	1214.6	0.0113280	0.0118000
1	0.0001180	179.9	183.9	1214.6	1262.7	0.0118000	0.0122720
1	0.0001180	183.9	187.9	1262.7	1312.7	0.0122720	0.0127440
1	0.0001180	187.9	191.9	1312.7	1364.7	0.0127440	0.0132160
1	0.0001180	191.9	195.9	1364.7	1418.5	0.0132160	0.0136880
1	0.0001180	195.9	199.9	1418.5	1474.2	0.0136880	0.0141600
Ray exceeded maximum range within Intralayer CSC - values before and after maximum range recalculation are							
1	0.0001180	199.9	203.9	1474.2	1474.2	0.0141600	0.0141600
1	0.0001180	199.9	200.0	1474.2	1475.3	0.0141600	0.0141694

Transprofile CSC determines range terminating conditions met. Any or all values of range (x_1) and height (z_1) may be returned to the calling TESS CSCI depending upon the TESS CSCI application. While not a part of the RTT, figure 3.2.2-1 illustrates a graphic of all intermediate range/height values as a visualization aid in test evaluation.

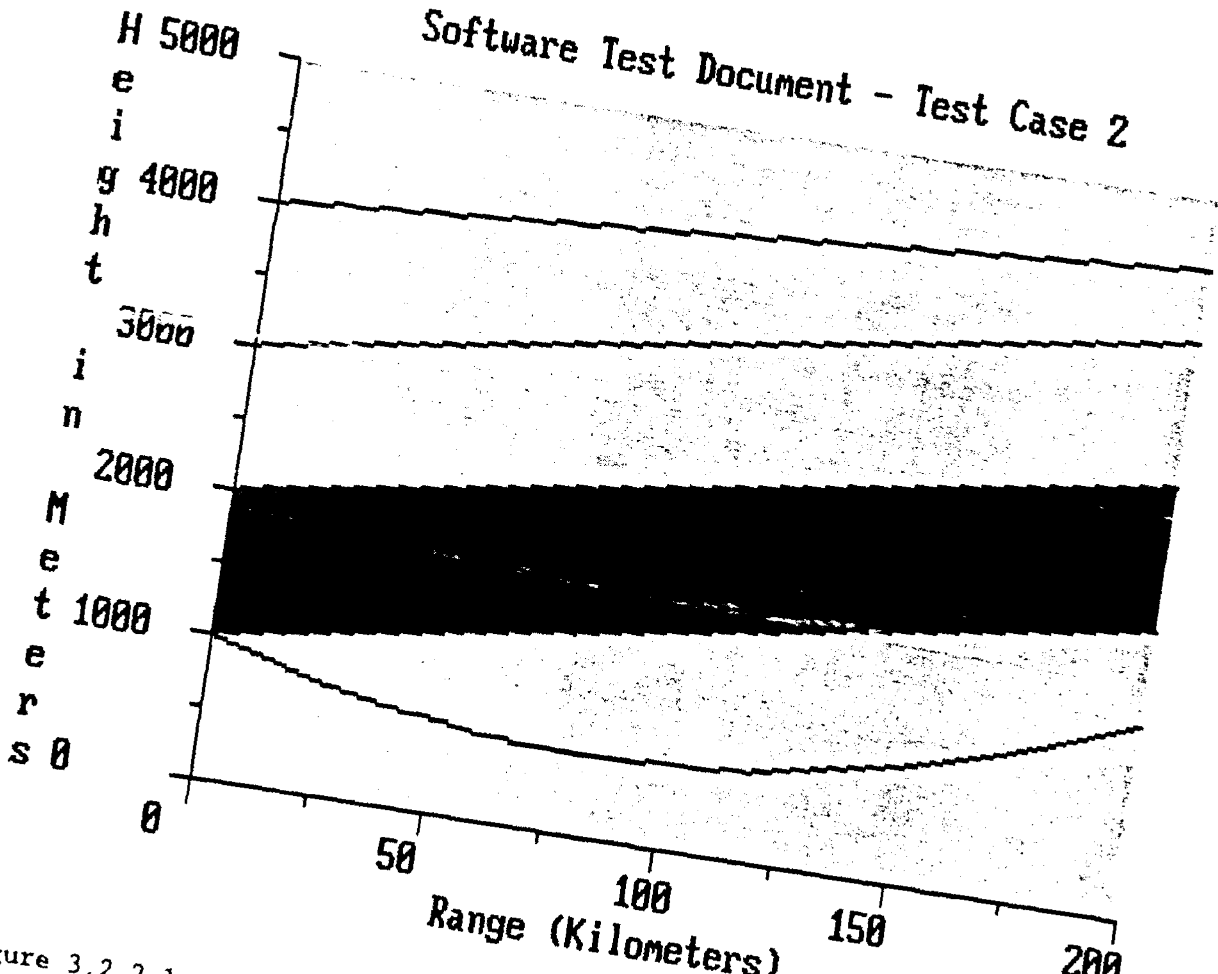

Figure 3.2.2-1. Test case 2 graphic display of intermediate results.

3.2.3 Criteria for Evaluating Results

The calculated range and height must be ± 1 of the least significant digit of the final values of table 3.2.2-1.

3.2.4 Test Procedure

The test procedure is as specified in section 3.1.4.

3.2.5 Assumptions and Constraints

Input data elements are assumed to be constrained by the limits listed within table 3.4-1 of the Software Requirements Specification.

3.3 Test Case 3

The purpose of this test case is to

a. Exercise the Intralayer CSC by
   (1) determining the proper M-unit gradient to use as a starting condition when a profile contains an artificial level with a vertical M-unit gradient of zero.

3.3.1 Test Inputs

Variable names, description, units, and input values for test case 3 are listed in table 3.3.1-1.

Table 3.3.1-1. Test case 3 data element inputs.

	Profile 1		Profile 2	
Level	Height (m)	M-unit (M)	Height (m)	M-unit (M)
1	.0	340.0	.0	340.0
2	1000.0	458.0	1000.0	458.0
3	1000.0	458.0	2000.0	400.0
4	3000.0	694.0	3000.0	518.0
5	4000.0	812.0	4000.0	636.0
6	5000.0	930.0	5000.0	754.0

f_{res}	Range step resolution factor	=	50
$pnumbr$	Number of profiles	=	2
$lnumbr$	Number of profile levels	=	6
$xdist_1$	Range to first profile	=	0 km
$xdist_2$	Range to second profile	=	200 km
z_{tran}	Antenna height	=	1000 m
α_{start}	Initial angle	=	-.0436332 radians

3.3.2 Expected Test Results

Variable names, description, units, and expected test results for test case 3 are listed in table 3.3.2-1.

Table 3.3.2-1. Expected test results from test case 3.

a. Exercise of Init CSC to establish constants.

L	level slopes $\Delta z/\Delta x_{p,L}$ $p=1$	$p=2$
1	.0000000	.0000000
2	.0000000	.0000000
3	5.0000000	.0000000
4	.0000000	.0000000
5	.0000000	.0000000
6	.0000000	.0000000

antenna level

$L_{tran} = 2$

b. Initial conditions computed by the Transprofile CSC.

profile counter (p)	=	1
level counter (L)	=	2
range step (x_{step})	=	4.0 km
intermediate tracing range (x_{now})	=	200.0 km
maximum propagation range (x_{max})	=	200 km
maximum propagation height (z_{max})	=	5000 m
beginning range (x_0)	=	0.0 km
beginning height (z_0)	=	1000.0 m
beginning angle (α_0)	=	-.0392699 radians

Table 3.3.2-1. Expected test results from test case 3 (cont).

c. Exercise of Intralayer, Translayer, and Mgrad CSCs to determine intermediate ranges, heights, angles, M-unit gradients, and ray/layer boundary intercept points.

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
2	-0.0000580	0.0	4.0	1000.0	825.0	-0.0436332	-0.0438652
1	0.0001180	4.0	8.0	825.0	650.5	-0.0438652	-0.0433932
1	0.0001180	8.0	12.0	650.5	477.9	-0.0433932	-0.0429212
1	0.0001180	12.0	16.0	477.9	307.1	-0.0429212	-0.0424492
1	0.0001180	16.0	20.0	307.1	138.3	-0.0424492	-0.0419772
Ray reflected from surface - value before calling and returned by Translayer CSC are							
1	0.0001180	20.0	24.0	138.3	-28.7	-0.0419772	-0.0415052
1		20.0	23.3	138.3	0.0	-0.0419772	0.0415867

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1000.0	1000.0	0.0	0.0

Values returned from Intralayer CSC are

1	0.0001180	23.3	27.3	0.0	167.3	0.0415867	0.0420587
1	0.0001180	27.3	31.3	167.3	336.5	0.0420587	0.0425307
1	0.0001180	31.3	35.3	336.5	507.5	0.0425307	0.0430027
1	0.0001180	35.3	39.3	507.5	680.5	0.0430027	0.0434747
1	0.0001180	39.3	43.3	680.5	855.3	0.0434747	0.0439467

Table 3.3.2-1. Expected test results from test case 3 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Ray penetrated upward into layer 2 - value before calling and returned from Translayer CSC are							
1	0.0001180	43.3	47.3	855.3	1032.1	0.0439467	0.0444187
2		43.3	46.6	855.3	1000.0	0.0439467	0.0437566

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1000.0	1000.0	0.0	0.0

Values returned from Intralayer CSC are							
2	-0.0000580	46.6	50.6	1000.0	1174.6	0.0437566	0.0435246
Ray penetrated upward into layer 3 - value before calling and returned from Translayer CSC are							
2	-0.0000580	50.6	54.6	1174.6	1348.2	0.0435246	0.0432926
3		50.6	52.6	1174.6	1263.1	0.0435246	0.0437650

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1252.9	1272.9	1000.0	1000.0

Values returned from Intralayer CSC are							
3	0.0001180	52.6	56.6	1263.1	1439.1	0.0437650	0.0442371
3	0.0001180	56.6	60.6	1439.1	1617.0	0.0442371	0.0447091
3	0.0001180	60.6	64.6	1617.0	1796.8	0.0447091	0.0451811
3	0.0001180	64.6	68.6	1796.8	1978.5	0.0451811	0.0456531

Table 3.3.2-1. Expected test results from test case 3 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
3	0.0001180	68.6	72.6	1978.5	2162.0	0.0456531	0.0461251
3	0.0001180	72.6	76.6	2162.0	2347.5	0.0461251	0.0465971
3	0.0001180	76.6	80.6	2347.5	2534.8	0.0465971	0.0470691
3	0.0001180	80.6	84.6	2534.8	2724.0	0.0470691	0.0475411
3	0.0001180	84.6	88.6	2724.0	2915.1	0.0475411	0.0480131
Ray penetrated upward into layer 4 - value before calling and returned from Translayer CSC are							
3	0.0001180	88.6	92.6	2915.1	3108.1	0.0480131	0.0484851
4		88.6	90.4	2915.1	3000.0	0.0480131	0.0482212

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
3000.0	3000.0	1443.1	1463.1

Values returned from Intralayer CSC are							
4	0.0001180	90.4	94.4	3000.0	3193.8	0.0482212	0.0486932
4	0.0001180	94.4	98.4	3193.8	3389.5	0.0486932	0.0491652
4	0.0001180	98.4	102.4	3389.5	3587.2	0.0491652	0.0496372
4	0.0001180	102.4	106.4	3587.2	3786.6	0.0496372	0.0501092
4	0.0001180	106.4	110.4	3786.6	3988.0	0.0501092	0.0505812

Table 3.3.2-1. Expected test results from test case 3 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Ray penetrated upward into layer 5 - value before calling and returned from Translayer CSC are							
4	0.0001180	110.4	114.4	3988.0	4191.3	0.0505812	0.0510532
5		110.4	110.6	3988.0	4000.0	0.0505812	0.0506091

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
4000.0	4000.0	3000.0	3000.0

Layer	M-gradient	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
5	0.0001180	110.6	114.6	4000.0	4203.4	0.0506091	0.0510811
5	0.0001180	114.6	118.6	4203.4	4408.7	0.0510811	0.0515531
5	0.0001180	118.6	122.6	4408.7	4615.8	0.0515531	0.0520251
5	0.0001180	122.6	126.6	4615.8	4824.9	0.0520251	0.0524971
Ray exceeded maximum height - value before calling and returned from Translayer CSC are							
5	0.0001180	126.6	130.6	4824.9	5035.8	0.0524971	0.0529691
6		126.6	129.9	4824.9	5000.0	0.0524971	0.0530403

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
5000.0	5000.0	4000.0	4000.0

Transprofile CSC determines height terminating conditions met. Any or all values of range (x_1) and height (z_1) may be returned to the calling TESS CSCI depending upon the TESS CSCI application. While not a part of the RTT, figure 3.3.2-1 illustrates a graphic of all intermediate range/height values as a visualization aid in test evaluation.

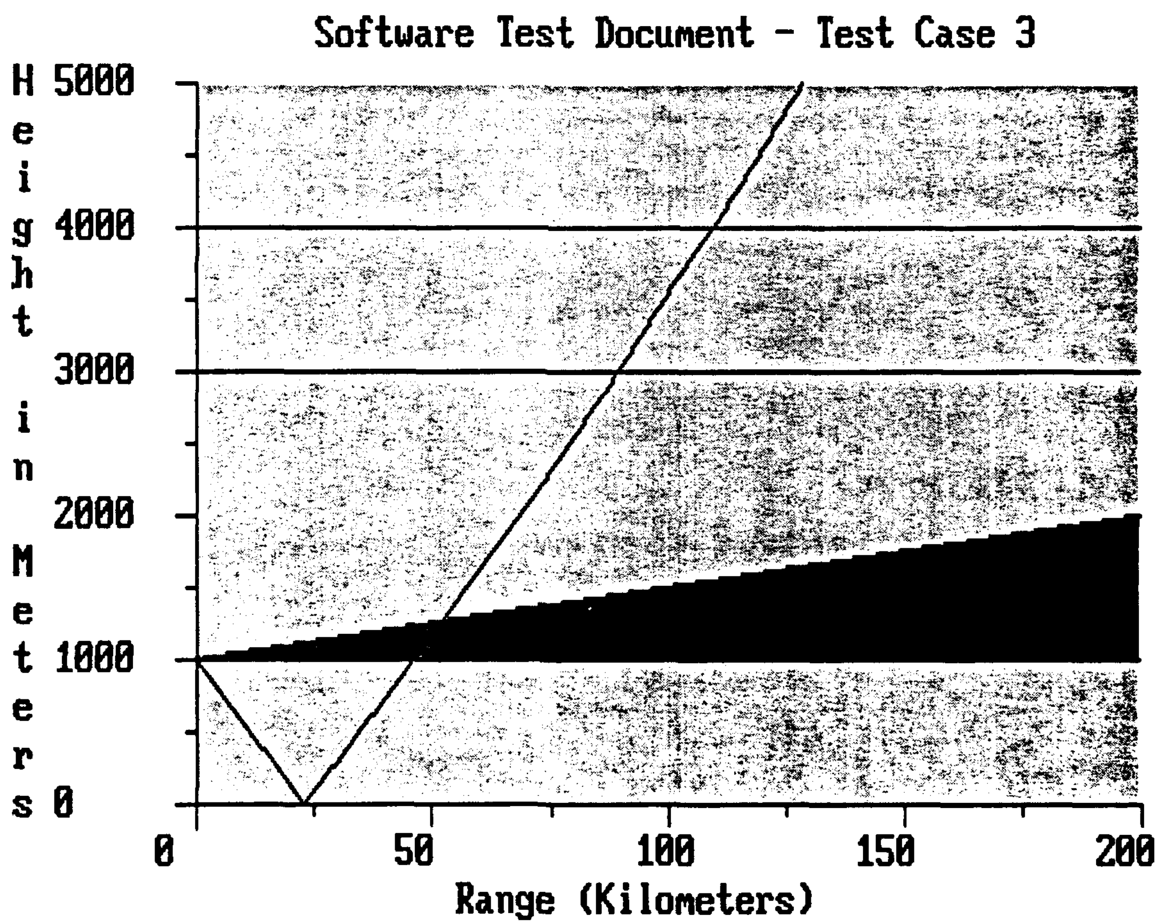

Figure 3.3.2-1. Test case 3 graphic display of intermediate results.

3.3.3 Criteria for Evaluating Results

The calculated range and height must be ± 1 of the least significant digit of the final values of table 3.3.2-1.

3.3.4 Test Procedure

The test procedure is as specified in section 3.1.4.

3.3.5 Assumptions and Constraints

Input data elements are assumed to be constrained by the limits listed within table 3.4-1 of the Software Requirements Specification.

3.4 Test Case 4

The purpose of this test case is to

a. Exercise the Transprofile CSC by
   (1) determining a new range step and intermediate tracing range upon Transition from one profile to the next.

b. Exercise the Intralayer CSC by
   (1) determining for a zero M-unit gradient layer, an ending range, height, and angle within the layer.

c. Exercise the Translayer CSC by
   (1) computing a range, height, and angle at a ray/layer boundary intercept under conditions of a zero M-unit gradient layer, a positive and negative penetration angle, and a zero and negative sloping boundary.

3.4.1 Test Inputs

Variable names, description, type, units, and input values for test case 4 are listed in table 3.4.1-1.

Table 3.4.1-1: Test case 4 data element inputs.

	Profile 1		Profile 2		Profile 3	
Level	Height (m)	M-unit	Height (m)	M-units	Height (m)	M-units
1	.0	340.0	.0	340.0	.0	340.0
2	2000.0	576.0	1000.0	458.0	2000.0	576.0
3	3000.0	576.0	2000.0	458.0	3000.0	576.0
4	4000.0	694.0	4000.0	694.0	4000.0	694.0
5	5000.0	812.0	5000.0	812.0	5000.0	812.0

f_{res}	Range step resolution factor	=	25
pnumbr	Number of profiles	=	3
lnumbr	Number of profile levels	=	5
$xdist_1$	Range to first profile	=	0 km
$xdist_2$	Range to second profile	=	275 km
$xdist_3$	Range to third profile	=	400 km
z_{tran}	Antenna height	=	2500 m
α_{start}	Initial angle	=	-.0218166 radians

3.4.2 Expected Test Results

Variable names, description, units, and expected test results for test case 4 are listed in table 3.4.2-1.

Table 3.4.2-1. Expected test results from test case 4.

a. Exercise of Init CSC to establish constants.

level slopes

$\Delta z/\Delta x_{p,L}$

L	$p=1$	$p=2$	$p=3$
1	.0000000	.0000000	.0000000
2	-3.6363637	8.0000000	.0000000
3	-3.6363637	8.0000000	.0000000
4	.0000000	.0000000	.0000000
5	.0000000	.0000000	.0000000

antenna level

$L_{tran} = 2$

b. Initial conditions computed by the Transprofile CSC.

profile counter (p)	= 1
level counter (L)	= 2
range step (x_{step})	= 11.0 km
intermediate tracing range (x_{now})	= 275.0 km
maximum propagation range (x_{max})	= 400 km
maximum propagation height (z_{max})	= 5000 m
beginning range (x_0)	= 0.0 km
beginning height (z_0)	= 2500.0 m
beginning angle (α_0)	= -.0218166 radians

Table 3.4.2-1. Expected test results from test case 4 (cont).

c. Exercise of Intralayer, Translayer, and Mgrad CSCs to determine intermediate ranges, heights, angles, M-unit gradients, and ray/layer boundary intercept points.

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned by the Intralayer CSC are							
2	0.0000000	0.0	11.0	2500.0	2260.0	-0.0218166	-0.0218166
2	0.0000000	11.0	22.0	2260.0	2020.0	-0.0218166	-0.0218166
Ray penetrated downward into layer 1 - values before calling and returned from Translayer CSC are							
2	0.0000000	22.0	33.0	2020.0	1779.9	-0.0218166	-0.0218166
1		22.0	27.5	2020.0	1900.0	-0.0218166	-0.0218166

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
2920.0	2880.0	1920.0	1880.0

Layer	M-gradient	x_0	x_1	z_0	z_1	α_0	α_1
Values returned from Intralayer CSC are							
1	0.0001180	27.5	38.5	1900.0	1667.2	-0.0218166	-0.0205186
1	0.0001180	38.5	49.5	1667.2	1448.6	-0.0205186	-0.0192206
1	0.0001180	49.5	60.5	1448.6	1244.3	-0.0192206	-0.0179226
1	0.0001180	60.5	71.5	1244.3	1054.3	-0.0179226	-0.0166246
1	0.0001180	71.5	82.5	1054.3	878.6	-0.0166246	-0.0153266
1	0.0001180	82.5	93.5	878.6	717.1	-0.0153266	-0.0140286
1	0.0001180	93.5	104.5	717.1	569.9	-0.0140286	-0.0127306
1	0.0001180	104.5	115.5	569.9	437.0	-0.0127306	-0.0114326
1	0.0001180	115.5	126.5	437.0	318.4	-0.0114326	-0.0101346

Table 3.4.2-1. Expected test results from test case 4 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned by the Intralayer CSC are							
1	0.0001180	126.5	137.5	318.4	214.1	-0.0101346	-0.0088366
1	0.0001180	137.5	148.5	214.1	124.0	-0.0088366	-0.0075386
1	0.0001180	148.5	159.5	124.0	48.2	-0.0075386	-0.0062406
Ray reflected from the surface - values before calling and returned from Translayer CSC are							
1	0.0001180	159.5	170.5	48.2	-13.3	-0.0062406	-0.0049426
1		159.5	167.9	48.2	0.0	-0.0062406	0.0052499

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1420.0	1380.0	0.0	0.0

Values returned from Intralayer CSC are							
1	0.0001180	167.9	178.9	0.0	64.9	0.0052499	0.0065479
1	0.0001180	178.9	189.9	64.9	144.1	0.0065479	0.0078459
1	0.0001180	189.9	200.9	144.1	237.5	0.0078459	0.0091439
1	0.0001180	200.9	211.9	237.5	345.2	0.0091439	0.0104419
1	0.0001180	211.9	222.9	345.2	467.2	0.0104419	0.0117399
1	0.0001180	222.9	233.9	467.2	603.5	0.0117399	0.0130379
1	0.0001180	233.9	244.9	603.5	754.1	0.0130379	0.0143359
1	0.0001180	244.9	255.9	754.1	918.9	0.0143359	0.0156339

Table 3.4.2-1. Expected test results from test case 4 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0, z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Ray penetrated upward into layer 2 - values before calling and returned from Translayer CSC are							
1	0.0001180	255.9	266.9	918.9	1098.0	0.0156339	0.0169319
2		255.9	263.5	918.9	1041.7	0.0156339	0.0156339

Layer Heights (m)

T_{x_0}	T_{x_1}	B_{x_0}	B_{x_1}
1069.5	1029.5	0.0	0.0

Values returned from Intralayer CSC are							
2	0.0000000	263.5	274.5	1041.7	1213.7	0.0156339	0.0156339
Ray exceeded range intermediate tracing range (x_{now}) within Intralayer CSC by crossing beyond profile 2 - values before calling and returned from Transprofile CSC are							
2	0.0000000	274.5	285.5	1213.7	1213.7	0.0156339	0.0156339
2	0.0000000	274.5	275.0	1213.7	1221.1	0.0156339	0.0156339

range step (x_{step}) = 5.0 km
intermediate tracing range (x_{now}) = 400.0 km

Values returned from Intralayer CSC are:							
2	0.0000000	275.0	280.0	1221.1	1299.2	0.0156339	0.0156339
2	0.0000000	280.0	285.0	1299.2	1377.4	0.0156339	0.0156339
2	0.0000000	285.0	290.0	1377.4	1455.6	0.0156339	0.0156339
2	0.0000000	290.0	295.0	1455.6	1533.8	0.0156339	0.0156339

Table 3.4.2-1. Expected test results from test case 4 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are:							
2	0.0000000	295.0	300.0	1533.8	1611.9	0.0156339	0.0156339
2	0.0000000	300.0	305.0	1611.9	1690.1	0.0156339	0.0156339
2	0.0000000	305.0	310.0	1690.1	1768.3	0.0156339	0.0156339
2	0.0000000	310.0	315.0	1768.3	1846.5	0.0156339	0.0156339
2	0.0000000	315.0	320.0	1846.5	1924.6	0.0156339	0.0156339
2	0.0000000	320.0	325.0	1924.6	2002.8	0.0156339	0.0156339
2	0.0000000	325.0	330.0	2002.8	2081.0	0.0156339	0.0156339
2	0.0000000	330.0	335.0	2081.0	2159.2	0.0156339	0.0156339
2	0.0000000	335.0	340.0	2159.2	2237.4	0.0156339	0.0156339
2	0.0000000	340.0	345.0	2237.4	2315.5	0.0156339	0.0156339
2	0.0000000	345.0	350.0	2315.5	2393.7	0.0156339	0.0156339
2	0.0000000	350.0	355.0	2393.7	2471.9	0.0156339	0.0156339
2	0.0000000	355.0	360.0	2471.9	2550.1	0.0156339	0.0156339
2	0.0000000	360.0	365.0	2550.1	2628.2	0.0156339	0.0156339
2	0.0000000	365.0	370.0	2628.2	2706.4	0.0156339	0.0156339
2	0.0000000	370.0	375.0	2706.4	2784.6	0.0156339	0.0156339
Ray penetrated upward into layer 3 - value before calling and returned from Translayer CSC are							
2	0.0000000	375.0	380.0	2784.6	2862.8	0.0156339	0.0156339
3		375.0	377.0	2784.6	2816.2	0.0156339	0.0156339

Layer Heights (m)

$^{T}x_0$	$^{T}x_1$	$^{B}x_0$	$^{B}x_1$
2800.0	2840.0	1800.0	1840.0

Table 3.4.2-1. Expected test results from test case 4 (cont).

Layer	M-gradient $\Delta M/\Delta z_{x_0,z_0}$	Range (km) x_0	x_1	Height (m) z_0	z_1	Angle (radians) α_0	α_1
Values returned from Intralayer CSC are							
3	0.0001180	377.0	382.0	2816.2	2895.8	0.0156339	0.0162239
3	0.0001180	382.0	387.0	2895.8	2978.4	0.0162239	0.0168139
3	0.0001180	387.0	392.0	2978.4	3063.9	0.0168139	0.0174039
3	0.0001180	392.0	397.0	3063.9	3152.4	0.0174039	0.0179939
Ray exceeded maximum range within Intralayer CSC - values before and after maximum range recalculation							
3	0.0001180	397.0	402.0	3152.4	3152.4	0.0179939	0.0179939
3		397.0	400.0	3152.4	3206.6	0.0179939	0.0183456

Transprofile CSC determines range terminating conditions met. Any or all values of range (x_1) and height (z_1) may be returned to the calling TESS CSCI depending upon the TESS CSCI application. While not a part of the RTT, figure 3.4.2-1 illustrates a graphic of all intermediate range/height values as a visualization aid in test evaluation.

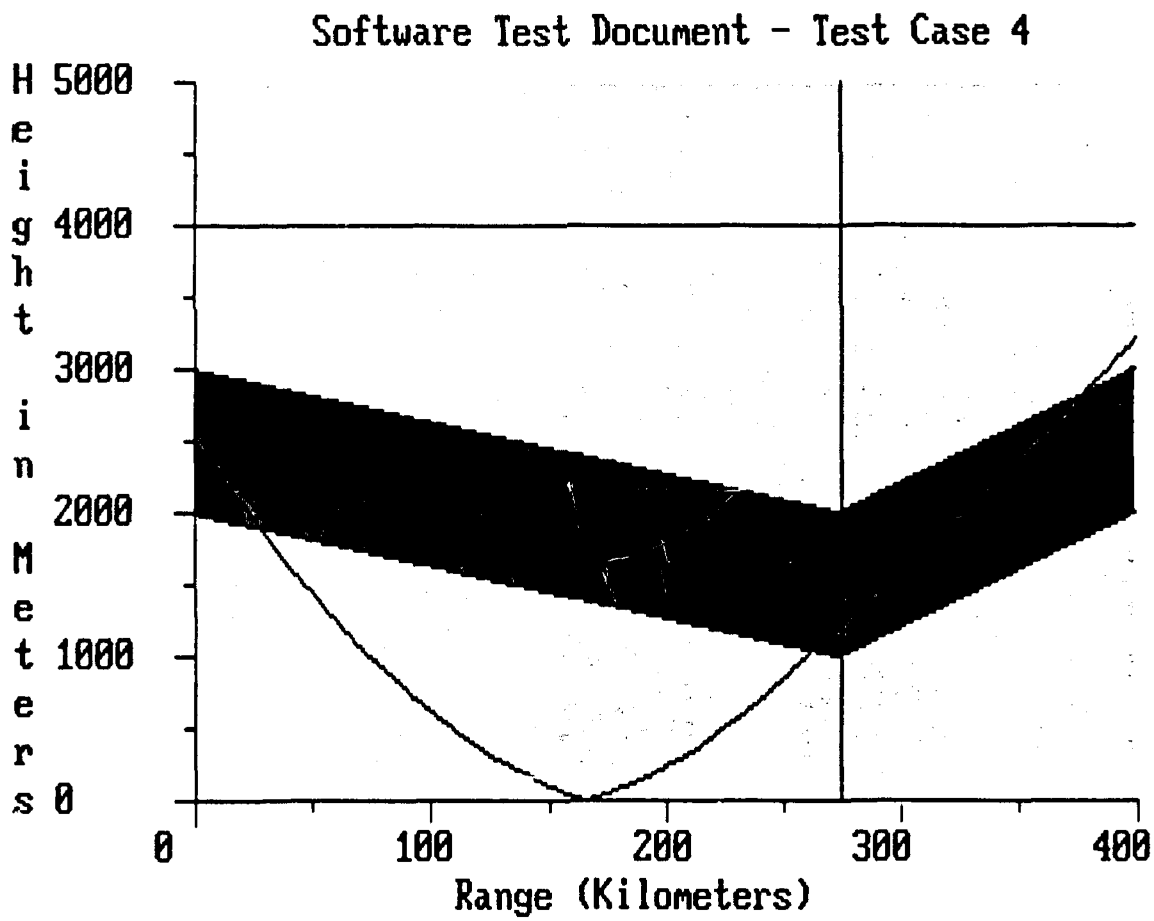

Figure 3.4.2-1. Test case 4 graphic display of intermediate results.

3.4.3 Criteria for Evaluating Results

The calculated range and height must be ± 1 of the least significant digit of the final values of table 3.4.2-1.

3.4.4 Test Procedure

The test procedure is as specified in section 3.1.4.

3.4.5 Assumptions and Constraints

Input data elements are assumed to be constrained by the limits listed within table 3.4-1 of the Software Requirements Specification.

4.0 NOTES

The following is listing of all variable names and meanings used in this document.

α_0	Ray segment's beginning angle
α_1	Ray segment's ending angle
α_{start}	Initial ray angle
B_{x_0}	Layer bottom boundary height at beginning range
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
$\Delta M/\Delta z_{x_0,z_0}$	M-unit gradient at the ray segment's beginning point
$\Delta z/\Delta x_{p,L}$	Layer boundary slope corresponding to the Lth level within the pth profile
res	Range step resolution factor
L	Level counter
L_{tran}	Level number corresponding to the bottom boundary of the layer containing the antenna height.
lnumbr	Number of profile levels
M	Modified refractivity
p	Profile counter
pnumbr	Number of profiles
RTT	Raytrace technique

TESS	Tactical Environmental Support System
T_{x_0}	Layer top boundary height at ray segment's beginning range
T_{x_1}	Layer top boundary height at ray segment's ending range
x_0	Ray segment's beginning range
x_1	Ray segment's ending range
$xdist_p$	Range from 1st to *p*th profile
x_{max}	Maximum propagation range
x_{mid}	Ray segment's midpoint range
x_{now}	Intermediate tracing range, i.e., the range between the two adjacent profiles currently under consideration.
x_{step}	Range step
z_0	Ray segment's beginning height
z_1	Ray segment's ending height
z	Height
z_{max}	Maximum propagation height
z_{tran}	Antenna height

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